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CAMPBELL BROWN
ON
DEPOSITS IN PIPES
AND
CHADWICK AND BLOUNT
ON THE
PURIFICATION OF WATER.

6 JUN 1879

DEPOSITS IN PIPES AND OTHER CHANNELS CONVEYING POTABLE WATER.

BY

PROFESSOR JAMES CAMPBELL BROWN, D.Sc.

AND

THE PURIFICATION OF WATER HIGHLY CHARGED WITH VEGETABLE MATTER;

WITH

SPECIAL REFERENCE TO THE EFFECT OF AERATION.

BY

OSBERT CHADWICK, C.M.G., M. INST. C.E.

AND

BERTRAM BLOUNT, ASSOC. INST. C.E.

WITH AN ABSTRACT OF THE DISCUSSION UPON THE PAPERS.

EDITED BY

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SECRETARY.

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SECT. I.—MINUTES OF PROCEEDINGS.

15 December, 1903.

Sir WILLIAM H. WHITE, K.C.B., D.Sc., LL.D., F.R.S., President, in the Chair.

(*Paper No. 3453.*)

"Deposits in Pipes and other Channels Conveying Potable Water."

By Professor JAMES CAMPBELL BROWN, D.SC.

THE various deposits which lessen the carrying-capacity of water-pipes, culverts and tunnels range themselves naturally under three classes :—

I. Incrustations on unprotected or imperfectly-protected iron pipes.
II. Deposits on the inner surface alike of iron pipes, whether protected or unprotected, and of culverts, rock tunnels and other channels; the deposits depending in their nature on the composition of the water, and occurring over the whole of the surface covered by the water.
III. Accumulations of débris in inverts, on hollows and irregularities in the water-channels, and in the *culs-de-sac.*

I. INCRUSTATIONS ON UNPROTECTED IRON PIPES.

Incrustations are formed by the corrosion of iron pipes, valves and other ironwork, where the inner surfaces are not protected by a layer of pitch, or where the protecting layer is imperfect.

These incrustations begin as minute projections dotted all over the pipes in very varied numbers—sometimes in rows, sometimes in an irregular manner. In form they resemble the limpets to be found on a rocky sea-coast; they are more or less conical in shape, often with a steep and a more sloping side, and grow by addition of concentric layers. The steep side faces the current. They increase in size and in number, until in badly-protected pipes they ultimately become confluent, and form a coating of considerable thickness. This kind of incrustation may be nearly uniform from the commencement, in which case nodules are not then seen; but the nature of the incrustation is the same. A pipe of small calibre is sometimes completely blocked by the incrustation. In large pipes the thickness of the deposit does not appear to be unlimited. In old pipes, when the incrustation is about 1 inch to 1½ inch thick it does not seem to increase, possibly owing to the density of the incrustation acting as a protection; but if the incrustation is removed, or if the conical tips of the "limpets" are broken off, it begins to grow again with renewed activity. For this reason it is unadvisable to use a scraper for removing the nodules or incrustations. The obstruction is only temporarily removed, and if the use of the scraper is continued, the life of the pipe is greatly reduced by the more rapid corrosion of the iron.

Fig. 1, Plate 1, shows a broken iron pipe with incrustations. Fig. 2 shows limpet-shaped incrustations beginning to become confluent. Fig. 3 is a section of one of the limpets. The central portion is black when fresh, and soft. It often contains a little sulphide of iron as well as oxide; it becomes red on exposure to air; the middle layers are often orange-red ferric oxide, and sometimes contain iron-organisms of the well-known rosary form (Figs. 4 and 5), which a high magnification resolves into a double ribbon-shaped spiral twisted closely upon itself. The limpet-shaped cones vary in consistence; when well developed they are hard outside and softer within. The outer concentric layers are denser, sometimes quite hard; they are composed of ferric oxide, but include hard black layers of magnetic oxide of iron, in which dead organisms can occasionally be found. The interior is softer; generally black when fresh, but becoming red on exposure. Sometimes there are orange layers between the black interior and the hard outer crust.

It has been suggested that the incrustations are produced or started by iron-organisms; and again, that they are the result of acids in the water acting on the iron of the pipes. Observation of a variety of examples in Great Britain and Ireland and in other countries disproves each of these conjectures. Although organisms are found in some incrustations, and may modify their composition, yet incrustations are often free from every trace of life. They occur equally in waters which contain no iron-organisms (Nos. 1 and 9 in Table III. of the Appendix), and in waters from which all organisms have been removed (Nos. 1, 4, 5, and 12 after filtration, Table III.); and although acid waters and waters containing manganous salts no doubt hasten the corrosion of iron, nevertheless the Author finds incrustations to be formed not only by acid waters (Nos. 1, 2, 3, 12, 13 and 17), but by water which is neutral (No. 7), and even alkaline (Nos. 5, 9, 14 and 15). No incrustations are formed, however, when the iron is effectively protected by any means from contact with the water.

The iron of the incrustation is in all cases derived from the iron of the pipe. The incrustations occur in water containing no iron in solution, such as Nos. 7, 9, 14, 15; the iron of the pipe is always dissolved out to a considerable extent where they occur; and the pipe is soft, black, and spongy beneath the limpets. In a piece of incrusted pipe which had been subjected to the action of an alkaline water flowing through it for upwards of 40 years, the iron when fresh could be cut by a knife half-way through from the inner surface. The action is therefore not due to acidity in the water.

Many incrustations contain no trace of organisms; but so far as the Author's observations go, when present, organisms appear to modify the composition of the limpet. The rosary-shaped form (Figs. 4 and 5, Plate 1) does not belong to one organism only, but is assumed by several different organisms at a certain stage of growth. Wherever it occurs the Author has always found the usually black iron compound converted into red ferric oxide; he has frequently found remains of dead organisms forming a layer close to the hard magnetic-oxide layers near the exterior. These are short, and have not the rosary form; but they may be the same organism. The occurrence of sulphide in the interior may be due to reduction of sulphates in the water, either by anaerobic organisms, which the Author has never been able to detect, or by the chemical action of metallic iron. In the laboratory, weak solutions of sulphates have been reduced alike by cultivations of the soft black internal portions of limpets, and by filings of metallic iron. There is not enough sulphur in the metal of any pipe which the Author has analyzed to account for the sulphur sometimes found. The compositions of five specimens of incrustations are given in Table I. of the Appendix.

No chemical treatment, not even the neutralization of acid waters by slight excess of lime or of caustic soda, prevents the corrosion and incrustation of iron pipes. The only treatment quite effective is the coating of the iron pipe by a smooth and perfect layer of pitch. For this purpose the pitch must be as free as possible from such hydrocarbons as either volatilize or dissolve by long exposure to flowing water. It should be laid on to the hot clean iron; and as the first coat is liable to have pin-holes or air-holes, which become centres of "limpets," the pipes should always receive a second coat. The coating of pitch must be continuous and complete; it should be smooth and hard, but not so hard as to be brittle. It is difficult to secure a perfect coating, and not easy to find a supply of suitable pitch. Although the process is essentially the same as that employed by Dr. Angus Smith, the material and the process which go by his name in commerce are not very satisfactory. The first coat must be cooled before the second is applied, and the second "dip" must be neither so hot nor so prolonged as to melt the first coat. To repair the coating on a laid pipe-line, it is possible to lay on the pitch with a brush, but it is very difficult to make the layer sufficiently perfect in this way.

II. Deposits and Growths depending on the Composition of the Water.

Calcium Carbonate.—The first deposit depending on peculiar composition of the water is the translucent and semi-crystallized scale of calcium carbonate, formed by the escape of carbonic acid from water containing bicarbonate of lime. This kind of deposit has been so long and so well known that there is no necessity to do more than mention it. A good example of it is found in the ancient Roman aqueduct of the Pont du Gard, in France, where a lining about 1 foot in thickness was formed in the course of centuries, and reduced the carrying-capacity by something like one-half before the aqueduct was broken. Other examples are familiar in the pipes, large and small, which convey many hard waters. Boiling the water or agitating it hastens the deposition. The best treatment is the well-known process of Dr. Clark, which consists in adding an equivalent quantity of milk of lime and running off the clear water after settlement.

The organisms growing in these calcareous waters are chiefly Confervae, Desmids, and other plants in which green predominates; and these sometimes form a slimy layer on the inner surface of cold pipes.

Black Slime.—A second kind of deposit is a black, slimy lining formed wherever the flowing water is in contact with the sides of pipes, culverts or tunnels. This deposit contains a great deal of iron; but the iron is not derived from pipes, because the deposit occurs on protected as well as on unprotected pipes, and on stonework, woodwork, brick and rock surfaces, where the water has never been in contact with pipes, nor with ironwork of any kind. The deposit lessens the flow of water, not only by diminishing the sectional area of the pipes, but also by greatly decreasing the velocity of the water.

This slimy layer has been called peaty, but the Author has never been able to find any particle of peat in it.

The slime has been attributed to the deposition of matters suspended in the water: but matter mechanically carried down is deposited chiefly at the invert of a pipe or culvert, and accumulates in siphons and in other depressions in the water-channels when the current is not strong enough to carry it forward; whereas the slime here referred to forms as thick a layer at the top and on the sides of pitch-coated pipes as at the invert. The composition is essentially the same all round the pipe, except that more siliceous and rock or clay particles are entangled in it at the invert (see Analyses of slimes Nos. 1 and 2, in Table II.). Further, the composition is similar at the beginning and at the end of a pipe many miles long, after it has been conveying water for years (see Analysis No. 3). It has also been imagined that the particles adhere all round the pipe by their consistency and stickiness, and vortex action has been invoked to account for their equal distribution: but particles breaking loose do not, in fact, adhere to the sides of pipes; they are either carried along or fall to the bottom; while vortex action, if any, bears them along, rather than causes them to adhere to the top of the pipe.

Chemical Composition of Slime.—The chemical composition is shown by the analyses appended (Table II.). Examination of a large number of these deposits from several sources has shown that the dried slime contains a small quantity of vegetable carbon compounds, but no trace of peat; and that it consists mainly of organic matter containing much ferric hydrate together with manganic and manganous oxides, giving a black colour to the whole; while entangled in the mass are minute particles of rock, diatoms, and remains of various organisms, with a small quantity of precipitated iron oxides.

That the iron comes from the water, and not from the iron of the pipes, is proved by the following facts:—

1. Similar slime is found in rock tunnels before the water has been in contact with iron.

2. The slime is found as plentifully on the sides of pipes completely protected by a coating of pitch as on uncoated iron.

3. The water always contains iron when slime is found (see Analyses of waters Nos. 2, 3, 12, 13, etc.), while water from similar gathering-grounds, but containing little or no iron, does not produce this kind of slime (Analyses of waters Nos. 5, 7, 9, 15, etc.).

4. In a very long length of pipe, iron was found to predominate in the first few miles, while the quantity of iron decreased, and

manganese increased, in the last few miles. (Compare Analysis of slime No. 3 with Nos. 1 and 2.) The water was saturated with oxygen throughout the length of the main.

5. The amount of iron in a certain water was determined at different points on the same pipe-line on the same day, with the following result :—

	Parts per 100,000.
Water at starting contained total iron	0·045
After 15 miles in iron pipes imperfectly protected . . .	0·04
After filtration	0·024

During the winter of 1899, when examining specimens of slime, the Author observed—besides diatoms, broken crustaceans and other organisms frequently found in water from catchment-areas—a large number of the hyphae of what are known as iron-bacteria. These consist of threads or tubes which are at first pale, then coloured yellow; as they grow older they acquire a gelatinous sheath in which ferric hydrate is deposited; this thickens until it entirely obscures the original structure and apparently kills the oldest end of the organism, which breaks up into a tangled mass of gelatinous ferruginous organic matter, in which the structure is lost (Figs. 6, 9, 13, Plate 1). The Author observed that while the dead jelly adhered to the pipes, the tips were still growing, Fig. 7.

The relation of the remains of the original carbon compound to the ferric deposit in the mass of the dead slime is shown by observing a certain portion of slime, fixed under the microscope, and then slowly dissolving away the iron and manganese by oxalic acid, taking care to prevent as far as possible a change in the relative position of the parts. The gas evolved by the action of manganese dioxide on oxalic acid always spreads out the lighter parts of the structure in spite of every care (compare Figs. 9 and 13 with Figs. 10 and 14). The organic residue is paler than in the Figure. In order to render it more distinct for a photograph it is stained with methylene blue (Figs. 11, 12 and 14). These pale residues, after treatment by oxalic acid, are proved to be the broken-down remains of the carbon compounds of the organisms.

That the black slime is not due to peat is shown by the following facts :—

1. By analysis the dried substance yields :—

	5 Months Old. Per cent.	Very Old. Per cent.
Carbon	41·77	29·43
Hydrogen	8·77	8·64
Nitrogen	4·68	4·21
Oxygen	44·78	57·72
	100·00	100·00

2. No trace of peat has been found in any deposit from these waters; and in other waters in which particles of peat have been found at the consumer's tap, no appreciable quantity of slime is found in the pipes. Peat is not decolorized by oxalic acid, while the dark slime is. Fig. 17 shows decayed particles of peat after treatment with oxalic acid, but not stained by methylene blue.

3. Although decomposed peat does not give all the reactions of cellulose, the vegetable matter being somewhat altered by decomposition, yet it gives different reactions from the slime residues and has a different composition, the slime residue nearly resembling the composition of fresh organic jelly.

	Old Peat Residues Treated with Oxalic and Hydrochloric Acids. Per cent.
Carbon	55·47
Hydrogen	5·79
Nitrogen	3·15
Oxygen	35·59
	100·00
Oxide of iron removed by hydrochloric acid	5·2
Other mineral matters in ash	5·6
	110·8

4. The slime does not accumulate for several years, whereas peat would begin to be deposited in the first year.

5. The organic filaments are found in the covered-up mass where no peat, even if present in the water, could reach, on account of the ferruginous sheath. Everything except rock particles has come from solution in the flowing water.

6. An experiment was made by taking from a rock tunnel water which came in contact with no ironwork, carefully straining out all minute particles of peat or other solid matter, including growing organisms, through an exceedingly fine sieve, and then allowing the water to flow into pipes well protected by a layer of pitch. After 5 months a coating of black slime was formed all round the interior of the pipes, which had the composition shown in the analysis of slime No. 4 (p. 17).

The formation of this coating was watched by means of the microscope. First there appears a living and growing jelly adhering to the surface of the pipe; dots, and, some months later, spirilla-shaped organisms, appear in this jelly. Iron begins to be deposited not on but in the jelly; and ultimately there are long threads in the jelly, which acquire a sheath. The sheath thickens by deposition of iron oxide, and the living thread elongates more and more, the sheath following up the thread. A tangled mass results: the older portions become more tangled and dense: and all the time particles are mechanically entangled. Finally the organism dies at the older end and breaks down, losing its form, and becoming a gelatinous, flocculent mass of dark ochreous deposit, with the younger sheaths and living threads growing out of it, like Fig. 7. Treated with oxalic acid at this stage, the metals are dissolved, and disclose faintly the broken down and shapeless carbon compound of the disintegrated threads, some of the sheaths occasionally remaining visible. Figs. 18, 19 and 20 show stages in the first year's growth on the surface of coated pipes.

Theories of the Growth, etc., of Iron-organisms.—Organisms allied to those here described caused a great deal of trouble in 1879 in the Berlin waterworks, in 1889 at Rotterdam, and at various times in many other waterworks in Germany and Italy. Early observers saw that there are various organisms peculiar to waters containing iron, and it was thought that they could not live without iron. Cohn[1] thought iron oxide had some relation to the vegetable activity of the cell. Zopf[2] thought Cohn was wrong. Writing in 1882–5, Zopf considered the collection of the iron oxide to be a mere mechanical process, because, according to his observations, empty cells become coloured if placed in ferruginous waters by the iron passing into them. There is a fallacy in Zopf's reasoning, because in these and some similar organisms the iron oxide gets into the full and active cell.

Next, a student named Winogradsky[3] wrote a graduation essay, affirming, somewhat rashly, his opinion that these organisms use ferrous bicarbonate as food, whose decomposition and oxidation sustains vital energy, and plays a part in life similar to that which sulphuretted hydrogen plays in the sulphur-bacteria. This certainly cannot be true; for in some of the waters to which the Author has paid most attention, there was no ferrous bicarbonate at all, in fact, no bicarbonate of any kind; and in others there was hardly a trace of carbonate or bicarbonate. The Author had difficulty in getting these organisms to remain alive in very dilute ferrous bicarbonate without hay-infusion; but he succeeded in cultivating them in water containing simply an infusion of hay, when they of course excreted no iron; while on addition of ferric salts to the hay-infusion they developed ferruginous tangle as they did in a stream (Figs. 15 and 16). Fig. 15 shows organisms from slime developed in the laboratory in an infusion of hay with a little ferric salt added. Fig. 16 shows the same organisms developed in a Welsh stream.

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[1] F. Cohn, Beiträge zur Biologie der Pflanzen, Pt. ii. p. 127. Breslau, 1872.

[2] W. Zopf, "Die Spaltpilze." 3rd ed. In A. Schenk's "Handbuch der Botanik," Vol. iii. Pt. i. Breslau, 1884.

[3] S. Winogradsky, "Ueber Eisenbacterien," *Botanische Zeitung*, 1888, p. 261.

Molisch[1] of Graz, in 1892, arrived at the conclusion that the colour is not exclusively due to iron, and that Cohn's and Zopf's organisms developed well without the smallest quantity of iron being present. He disputes the opinion that the organisms take up ferrous iron. He points out that it should be possible to recognize iron in the cell, but he says it never is; and he thinks the jelly surrounding the sheath acts chiefly as a filter to keep back, store, and, if necessary, oxidise the iron without letting it pass into the cell. The Author's observations satisfy him that in this last respect Molisch was not correct, although his criticism of Winogradsky's views is undoubtedly correct, and it is certain that the oxidation of ferrous iron does not supply the vital energy.

The best account and classification of these organisms were given by Migula[2] of Carlsruhe. He names them *Chlamydothrix.*

According to the Author's observations, therefore, this kind of slimy deposit arises in the following way:—The germs and young forms of *Chlamydothrix* come down with the water, and can be found in it by filtration or centrifugal separation. They attach themselves to, and grow on, the inner surface of the pipes and channels. It is known to botanists that these organisms grow attached to something, rather than freely floating in water. First, there is a jelly with specks in it. These specks enlarge and become spiral, then long and twisted, and then become threads (Figs. 18, 19, 20, Plate 1) having a gelatinous sheath. Iron oxide is deposited in the gelatinous sheaths, which continue to thicken. The older part becomes choked and intertwined, dries, and disintegrates; while the thread-like organism pushes out at the free end, and the thickening sheath follows it up (Fig. 7). While these tangled filaments are growing, the solid particles in the water and broken-off floating organisms are caught and retained by the gelatinous threads. There may possibly be some chemical separation of the oxide of iron; if so, this becomes entangled also; but the oxide of iron comes chiefly from the well-known deposition in the jelly of the organisms; and in the waters which the Author has studied the iron is not set free from solution, except by the destruction of the carbon compounds which hold it in solution. The consumption of the carbon compounds is caused by the organisms living upon them. The oxide and dioxide of manganese, which occur in black patches and particles in the slime, have a different origin. Water containing traces of manganese salts forms by oxidation small concretions of dioxide or mixed oxides. This has been proved by examination of natural waters,[1] and by experiment in the laboratory. Particles of oxides of manganese thus chemically deposited are entangled also, and blacken the slime. If they and other solid particles were not entangled in the slime, they would be found at the bottom of the culvert, and not equally at the top and sides.

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[1] H. Molisch, "Die Pflanze in ihren Beziehungen zum Eisen," p. 63. Jena, 1892.

[2] W. Migula, "System der Bakterien," vol. i. Jena, 1897.

Conditions of the Growth of Slime in Natural Waters.—A comparison of natural waters will be of service in considering what conditions are favourable to the growth of slime, and what conditions are unfavourable.

Referring to the analyses of water (Appendix, Table No. III.), No. 12 is water collected from a surface having several peat-bogs and much upland pasture, and hardly any cultivation, on a bed of Silurian rock. There are several ferruginous springs on the gathering-ground. The water is always acid, although it contains neither carbonic acid nor carbonates, and no free mineral acid. It contains both iron and manganese; and only about 4 parts of total solids per 100,000, with a relatively large proportion of carbon compounds. This water yields much slime.

No. 2 is from a very similar gathering-ground. It contains 5½ parts of dissolved matter per 100,000, including organic acids, no ferrous iron, but 0·016 part ferric iron, and a trace of manganese. The hardness is 2·2, of which 0·52 is removed by boiling, and 1·69 is permanent. It is comparatively very acid, but contains few carbonates and no free mineral acids, yet much of the acidity remains on boiling. This water yields much slime, like Fig. 8. (See Analysis of slime No. 7.)

The gathering-ground of water No. 3 is similar, but has more cultivation on it. The water has 5·6 parts of dissolved matter, 0·6 organic carbon, 0·1 nitrogen. It is very soft, contains a quantity of iron and a trace of manganese. The acidity is equivalent to 0·22 lime, and is not removed by boiling. This water yields slime with long strings of iron-organisms.

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[1] H. S. Pattinson, Trans. Newcastle-on-Tyne Chemical Society, vol. iv., 1880, p. 219.

No. 13 is from a similar gathering-ground on Old Red Sandstone. It contained iron-organisms as well as other organisms, and yielded both slime and incrustations. All the above waters yielded slime full of the hyphae and remains of iron-organisms.

No. 14 water is from a similar gathering-ground to No. 13, on Upper Silurian rock. It contains 16·06 parts of dissolved matter per 100,000, only a trace of iron, and no manganese; but it contains large quantities of carbonates, and has an alkaline reaction. This water contained no iron-bacteria and formed no slime; but it did form an incrustation by the oxidation of iron pipes.

No. 1 is from an upland gathering-ground with pasture and moss-land very little cultivated. It is slightly acid to test-paper. Although a few iron-organisms have been found in it, there is no growth of slime in the pipes; but there is the usual incrustation on unprotected pipes.

No. 9 water is from a surface having a large area of peat moss, upland pasture, barren hills, and some cultivated land on gneiss and schist. It is almost neutral, but slightly alkaline. It forms no slime; the growth in the water-channels is represented by Fig. 21, Plate 1, and consists of freshwater sponges, with a few fungi and diatoms and other organisms. Incrustations on pipes carrying this water have the usual composition, as shown in Table I., Nos. 2, 3, and 4.

No. 7 water is from upland pasture and hill surface on crystalline schists, slate and grits, with peat and scarcely any cultivated land. It is nearly neutral, and if sometimes slightly acid it becomes alkaline on boiling, through escape of carbonic acid gas. It contains some peat, 0·21 part of organic carbon per 100,000, only a minute trace of iron, and no manganese. It forms incrustation on iron pipes, but no growth of slime.

No. 4 is from a hill gathering-ground with much peat, on primitive rocks, and is filtered. It contains 6·7 parts of dissolved matters per 100,000, including much organic matter, but hardly any iron. It has an acid reaction, but this disappears on boiling, and is therefore due to carbonic acid: after boiling, the water is just perceptibly alkaline. This water forms no slime, but forms incrustations on iron.

No. 5 is from low hills of primitive rock and some limestone. It contains in solution 9·9 parts of solids per 100,000, including a large proportion of organic matter and very little iron. The reaction is alkaline. The water forms no slime and no iron-organisms; the organisms found in it are chiefly of a green vegetable character, such as Desmids, etc.

No. 15 is from Lake Ontario. It contains 18·48 parts per 100,000 of total solids in solution and only 0·006 of iron. It is alkaline, forms no slime, and contains no iron-organisms. It does form incrustations on iron.

Two questions may now be considered, namely, what is the cause of the growth of ferruginous slime? and how can it be prevented?

Cause.—It is evident that acidity other than carbonic acid always characterizes water which produces this ferruginous slime; alkaline water never grows any, so far as the Author has seen, nor does neutral water. Bicarbonates, which imply lime and magnesia, seem to be opposed rather than favourable to the growth: organic matter alone does not produce it: and a trace of iron in neutral and alkaline water is quite consistent with absence of slime. But an appreciable quantity of iron in solution, in combination with organic matter of an acid character, is an invariable accompaniment of the slime. Traces of manganese are often present also, and produce a deposit of particles of manganese dioxide which darken the slime; but these are not essential. This is a purely chemical and mechanical phenomenon, and appears in water which exhibits no growth of slime—for example, the water analyzed by Mr. H. S. Pattinson in 1879, which has already been referred to.

It is hazardous to conjecture a solution of the iron phenomena, when so many observers have propounded, one after another, quite incorrect theories; but many circumstances point to some such explanation as the following:—The slime-organisms live on the carbon compounds in a soluble organic compound of iron, which penetrates into their substance, even into the inner tube. Whether the iron performs any function or not, the carbon compounds support life, and the iron oxide is necessarily deposited throughout the whole mass of living matter, but chiefly in the active parts. It thickens the sheath, until the organism, throwing out fresh tips at one end, dies at the other end and breaks up into the gelatinous matter which is seen when iron is removed from masses of slime by oxalic acid (Figs. 10, 11, 12, 14).

The deposition of manganese dioxide[1] is, the Author is satisfied, the result of oxidation by the oxygen dissolved in the water. Oxygen dissolves in water very quickly to the extent of about 6 volumes per thousand; and water was found to be saturated with oxygen after passing through 19 miles of pipe in which slime was growing. During its passage it had opportunities of replenishing its oxygen. On the other hand, the dissolved iron was reduced from 0·028 to 0·02 on passing through the same 19 miles.

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[1] The Author has seen a mass deposit of manganese dioxide on brickwork in a culvert accumulated in many years from water containing only a minute quantity of manganese salts.

Prevention.—Two modes of attack are open for the purpose of checking the growth of ferruginous slime on the inner surface of water-channels, namely, either by introducing conditions fatal to the growth of the organism, or by removing its food. Neutralization of the acidity of the water, by lime and by soda, has been tried experimentally. A modification of the Clark softening-process was employed, with the result that no iron-organism grew in the completely neutralized or slightly alkaline water, although side by side with the treated water, other pipes carrying untreated water developed jelly and well-marked iron-organisms in the same period of time.

The action of an alkali, or alkaline earth, does not precipitate the iron oxide; on the contrary, alkali causes the solution of the organic compound of iron by distilled water. Straining through the finest gauze does not prevent the growth of slime in the water afterwards, although it greatly delays it, and lessens the quantity in a given time. It is, however, only a question of time, and, ultimately, the slime grows again as before.

The result appears, so far, to be different with filtration, if thorough. In more than one water, within the Author's knowledge, filtration has prevented the appearance of the growth of slime beyond the filter-bed, although it does not diminish the growth of incrustations. Efficient filtration removes the organic matter, and so removes much of the iron held in combination with the organic acid; and the Author has never seen slime grow to any extent in water after good filtration. But there is evidence of a growth of organic jelly, containing oxide of iron, forming a thin film in pipes beyond efficient filter-beds; and it is conceivable that this may, after the lapse of sufficient time, grow in the same manner as before filtration, though at a slower rate.

The temporary removal of slimy growths can be effected by a convenient form of brush, devised by Mr. G. F. Deacon, M. Inst. C.E. This must be so soft as not to detach or break the incrustations, if any, beneath the slime. But it is far better to prevent the growth of slime, in waters favourable to it.

III. Loose Deposits.

These consist of mud, particles of rock and clay, remains of dead organisms; with which, in the case of ferruginous waters, are mixed portions of the slime broken off from the growth in the pipes by the flow of the water. Such deposits lie in the hollows of the pipe-line, and impede the flow at the lower parts and on the upward inclines. They are not confined to waters growing the ferruginous slime. These deposits can be removed by rapid sluicing or by brushing, and need no further mention here.

The Author has to thank Mr. James Mansergh, Past-President Inst. C.E., Mr. G. F. Deacon, Mr. Joseph Parry, Mr. W. M. Gale, Mr. W. Dyack, MM. Inst. C.E., and many other engineers, for information, samples and assistance in the course of these investigations; Mr. R. R. Tatlock of Glasgow, Mr. T. Jameson of Aberdeen, and other chemists, for analyses and information; and Professor R. J. Harvey Gibson, of Liverpool, for valuable advice.

The Paper is accompanied by twenty-one blocks, from which Plate 1 has been prepared, and by the following Appendix.

[Appendix.

APPENDIX.

TABLE I.—ANALYSES OF INCRUSTATIONS.

—	1 Young Incrustations produced in 5 months on uncoated iron pipes by No. 12 Water containing no iron organisms, its acidity neutralized by lime.	2 Old Incrustations on iron pipes from No. 9 Water, which contains no iron organisms, and has an alkaline reaction.	3 Conical Incrustations containing a hard magnetic layer, but no soft orange layer, and no sulphide. No. 9 Water, alkaline reaction.	4 Old Incrustations containing black sulphide in centre and an orange layer, with rosary-shaped organisms. No. 9 Water, alkaline reaction.	5 Incrustation removed from iron pipes by a scraper.
	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.
Moisture	2·62	9·4	5·61	4·88	2·74
Loss on ignition	24·19	20·5	21·38	18·34	10·96
Ferric oxide	57·95	61·87	58·48	59·46	76·2
Ferrous oxide	9·17	4·15	8·78	14·4	
Lime	2·06	0·56	0·23	..	0·075
Magnesia	trace	none	..	0·1	trace.
SO_3 combined	1·43	0·80	0·32	0·2	0·28
Sulphur	trace	..	0·34	0·05	
Insoluble in hydrochloric acid	2·58	1·79	4·81	1·55	7·2
Undetermined	..	0·93	0·05	1·02	2·545
	100·00	100·00	100·00	100·00	100·000

TABLE II.—ANALYSES OF SLIME.

—	1 Sides of pipe.	2 Bottom of same pipe.	3 Same pipe 11 miles farther on.	4 Slime on side of protected pipe (after 5 months' flow direct from rock tunnel).	Slime several Years old. 5 Slime. 19 April, 1900.	Slime several Years old. 6 Slime; 14 miles farther on, March 1901.	7 Mature Slime from No. 2 Water in protected pipes.
	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.
Ferric oxide	42·23	39·72	25·11	39·39	28·14	33·19	33·73
Ferrous oxide	none	none	none	trace	none	none	
Manganous oxide	5·98	6·65	19·91	17·38	17·17	11·82	16·58
Manganic peroxide	9·58	10·34	17·77	1·30	19·84	8·63	26·83
Lime	1·67	2·80	1·24	1·57	0·70	2·55	2·70
Magnesia	13·74	9·83	1·45	1·64	1·69	0·21	1·15
Sulphates	trace	trace	trace				
Sulphides	none	none	none				
Loss on ignition, combined water, animal and vegetable matter [1]	26·80	30·66	34·52	33·63	27·67	42·12	19·01
Undetermined	..	..	..	5·09	4·79	1·48	
	100·00	100·00	100·00	100·00	100·00	100·00	100·00
Sand and insoluble matter	24·66	37·18	36·7	43·89	48·04	13·27	14·23
Including carbon	8·17	..	9·98	..	5·97		
" nitrogen	..	..	1·47	..	0·85		

TABLE III.—ANALYSES OF WATERS.

(Expressed in parts per 100,000.)

—	No. 1 Water. Rivington.	No. 7 Water. Loch Katrine.	No. 9 Water. Dee, Aberdeenshire.	No. 12 Water. Vyrnwy.
Total solids	10·16	3·61	6·1	3·98
Loss on ignition	2·74	1·18	1·9	1·05
Alkalies	1·06	0·501	1·36	0·518
Magnesia	0·461	0·205	0·256	0·127
Lime	1·735	0·509	0·48	0·706
Oxides of iron	0·016	Fe_2O_3 0·002 FeO None	None	0·099
Manganese oxide	0·017	None	None	0·059
Chlorine, combined	1·5	0·711	1·14	0·6
SO_3 combined	2·144	0·435	0·476	0·6
Silica	0·463	..	0·361	0·214
Total mineral matter	7·417	..	..	2·923
CO_2 combined	None	0·308	..	None
Organic carbon	0·343	0·21	..	0·498
,, ,, after filtration	0·323	..	..	0·331
Organic nitrogen	0·064	..	..	0·064
,, ,, after filtration	0·052	..	..	0·042
N as nitrates	Trace	0·005	0·02	0·109
Acidity (as CaO)	0·19	Almost neutral; alkaline after boiling.	Alkaline.	0·2
Oxygen, per litre	..	..	..	5·45 c.c.
Nitrogen gas, per litre	..	..	..	11·53 c.c.
CO_2	..	..	..	None

TABLE III. (*continued*).—ANALYSES OF WATERS.

——	No. 2 Water. Elan Valley.	No. 3 Water. Another Welsh Valley.	No. 4 Water. Ireland.	No. 5 Water. Ireland.	No. 6 Water. Lancashire.	No. 13 Water. Taff.	No. 14 Water. Montgomeryshire.	No. 15 Water. Ontario.	No. 17 Water. Lancashire.
Total solids . .	5·44	5·6	6·72	9·92	34·8	4·8	16·06	18·48	10·44
Loss on ignition .	..	..	3·04	4·52	..	..	..	5·16	..
Oxides of iron . .	Fe_2O_3, 0·016 FeO, None	Small quantity	0·004	0·008	Trace	Small quantity	Trace	0·006	Small quantity
Manganese oxide .	Trace	Trace	..	..	Trace	Trace	None	None	Trace
Chlorine, combined	..	..	..	..	3·0	..	..	..	1·3
CO_2 combined . .	0·46	..	0·176	..	..	None	Large quantity	..	None
Organic carbon .	..	0·6	..	..	1·109	..	..	..	..
,, nitrogen .	..	0·1	..	..	0·124	..	..	..	..
Acidity (as CaO) .	0·225	0·22	Acid before boiling; alkaline after	Alkaline	Alkaline	Slightly acid	Alkaline reaction	Alkaline	Slightly acid
Hardness . . .	2·21°	..	1·95°	4·03°	14°	..	..	..	..

(*Paper No. 3460.*)

"The Purification of Water highly charged with Vegetabl Matter; with Special Reference to the Effect o Aeration."

By Osbert Chadwick, C.M.G., M. Inst. C.E., and Bertram Blount,
Assoc. Inst. C.E.

In this country, and in most European countries, the water-supply of large towns is usually obtained from rivers flowing through cultivated districts, or from gathering-grounds situated in remote or barren places; or, more rarely, from deep wells. The well-water is usually pure, and need not be considered here. The river-water, if, as is common, somewhat contaminated, is polluted with the sewage of towns above the intake, and by the surface-drainage from manured and cultivated land; the chief impurities to be looked for and removed are thus of animal origin. The water from mountain streams and moorland gathering-grounds is free from sensible contamination of this kind, but may contain organic matter of vegetable origin, usually of a peaty character. In temperate climates, however, the quantity of such matter is usually not excessive, and at worst causes the water to have a peaty colour and flavour. On account of the temperate climate and of the fact that the gathering-grounds are situated in high and unfertile regions, there is no liability to great and sudden growth of vegetation, followed by swift decay and consequent communication to the supply of the semi-oxidized products o vegetable refuse.

But in tropical and sub-tropical countries growth and decay of vegetation are of a rapidity and on a scale which have no parallel in temperate latitudes. If the débris from this decay finds access to the water-supply, serious organic contamination may result. It is evident that the probability of such contamination is much enhanced when the water is in a state of semi-stagnation, as may happen in a watercourse flowing slowly through marshy ground, or spreading into shallow pools. Much greater is the risk when the water is impounded in some large shallow pond, through which the flow is inconsiderable compared with the volume retained. When, on the other hand, the stream is brisk, and receives water from sources which are not commonly stagnant, the amount of vegetable impurity will be much reduced. It is found by experience that water of satisfactory quality can be collected from gathering-grounds covered with tropical vegetation, provided that there is no considerable contribution of water which has been stagnant in contact with decaying vegetable matter. The situation may be summed up by saying that, though a tropical water is not necessarily a bad water, yet it has, under like conditions of collection and storage, a larger opportunity of acquiring products of vegetable decay than has a similar water in a temperate region. Cases can be cited of all grades of water illustrating this point, from the best to the worst. It is to the worst cases, and to the treatment which the Authors have found appropriate, that they direct attention in this Paper.

Water containing a large amount of vegetable matter in solution is neither pleasant nor safe as a potable fluid. It is generally conceded that, though not always unpalatable, such water causes various stomachic complaints, notably diarrhœa; disorders of the kind have been observed with moorland waters of even non-tropical countries. This is the normal quality of tropical waters which have remained long in contact with growing and decaying vegetable matter. But at times—generally seasonal—there are great and relatively sudden alterations of the character of this vegetable-laden water. From being merely somewhat peaty and unattractive it may become positively offensive, with a stale fishy odour, and altogether undrinkable. The cause of this change is not certainly known, but it is probably to be traced to bacterial activity. With these conditions in view, it will be seen that to advise on the use and purification of tropical waters of this class is no easy task.

CHARACTER AND COMPOSITION OF WATERS HIGHLY CHARGED WITH VEGETABLE MATTER.

There is a striking similarity in the class of waters referred to, even though their places of origin are thousands of miles apart, and the local conditions by no means identical. The main governing causes appear to be a profusion of vegetable life quickly growing and rapidly decaying, and exposure of the water in a stagnant or semi-stagnant state to contact with the débris from these life-processes. Analyses of various samples from tropical and sub-tropical countries, given in the Paper and in Appendix I., serve to illustrate both this similarity and the difference which is to be observed between waters flowing freely and others semi-stagnant. In the first place, as a contrast to the highly charged waters about to be described, certain samples from Grenada will be considered, analyses of which have been made for the Government by Professor Harrison. They will suffice to show that water collected, as were these samples, in tropical districts and from land laden with vegetable growth of all kinds, is not necessarily polluted with products of decay: the possibility of that pollution no doubt existed; but its occurrence was prevented by the absence of areas of stagnation in the sources of supply. The following are the chief figures in the analyses which are of significance for the present purpose:—

GRENADA.

—	Samples.	
	No. 1.	No. 2.
	Grains per Gallon.	Grains per Gallon.
Total solids	7·50	8·50
Chlorine	0·71	0·85
	Parts per 100,000.	Parts per 100,000.
Free ammonia	0·002	0·001
Albuminoid ammonia	0·004	0·003
Oxygen absorbed (in 4 hours)	0·061	0·037
Nitrogen as nitrites	Nil	Nil
,, ,, nitrates	0·001	0·024
Hardness	3·8°	5·2°

These are both waters from running streams without stagnant places, and are substantially pure; they may be usefully compared with examples about to be given, and especially contrasted with those other tropical waters which are at the opposite end of the scale of purity.

That this condition of relative freedom from vegetable contamination is not uncommon, even in waters taken from sources surrounded by tropical vegetation, is shown by the following analyses made by one of the Authors:—

MOMBASA.

—	No. 1. Hill Stream.	No. 2. Stream in Main River (above Hill).
	Grains per Gallon.	Grains per Gallon.
Total solids	14·98	15·96
Chlorine	3·99	2·95
	Parts per 100,000.	Parts per 100,000.
Free ammonia	0·006	0·002
Albuminoid ammonia	0·003	0·014
Oxygen absorbed (after 4 hours)	0·06	0·11
Nitrogen as nitrites	Nil	Nil
„ „ nitrates	Nil	Trace
Hardness	3°	3°

Both these samples are from running streams. The first, indeed, is from an actual spring; the second is from a moderately swift stream, in which, however, there are some pools; it flows through a dense forest. The first is sensibly pure, but the second already gives signs of that class of contamination which will be shown later to be characteristic of tropical waters that have had opportunity of receiving the products of vegetable decay. The amount of free ammonia is low, that of the albuminoid ammonia is somewhat high, and that of the oxygen absorbed is substantial. There is an almost complete absence of oxidised nitrogen. These points are emphasized in the case of the following sample:—

RIVER PEMBRA.

(Shimba Hill Source.)

	Grains per Gallon.
Total solids	15·40
Chlorine	4·37
	Parts per 100,000.
Free ammonia	0·002
Albuminoid ammonia	0·015
Oxygen absorbed (after 4 hours)	0·20
Nitrogen as nitrites	Nil
„ „ nitrates	Nil

Hardness, 4·5°

The characteristically high albuminoid ammonia and oxygen absorbed occur here, and the equally characteristic absence of oxidised nitrogen is to be noted. The water is quite typical of its class. Other and more striking examples are given in Appendix I.

Comparison of a Tropical and a Non-tropical Water.—It has already been pointed out that the conditions of copious growth of vegetable organisms, of their rapid decay, and of ample opportunity for absorption of the products of decay by the water, determine the character of the contamination acquired by that water. In illustration of this point, two cases, dissimilar in all but these essential respects, may be cited.

One of the waters in question was collected from a pond at Rowledge, near Farnham, in Surrey. The other is from the Mare aux Vacoas, in the island of Mauritius. The two places are as different as can well be conceived, save for the fundamental facts (1) that they are exposed to the ingress of vegetable refuse, (2) that they are almost stagnant, and (3) that they are subject to little or no animal pollution. A more detailed description of the situation of the pond at Rowledge is given in Appendix II. (p. 42). In Appendix III. is a full account of the Mare aux Vacoas. Here it will be sufficient to quote the analyses of the two waters.

——	Rowledge.	Mauritius.
	Grains per Gallon.	Grains per Gallon.
Total solids	8·40	5·32
Chlorine	1·67	1·27
	Parts per 100,000.	Parts per 100,000.
Free ammonia	0·004	0·002
Albuminoid ammonia	0·064	0·064
Oxygen absorbed (4 hours)	0·64	0·42
Nitrogen as nitrites	Nil.	Nil.
,, ,, nitrates	Nil.	Nil.
Hardness	3·5°	2·5°

It is fortunate that it is rarely necessary in this country, or in Europe generally, to have recourse to water-supplies of this description; otherwise the difficulties of treatment about to be described in the case of the Mauritius water would be encountered, though doubtless in a less acute form.

THE TREATMENT AND PURIFICATION OF WATERS HIGHLY CHARGED WITH VEGETABLE MATTER.

The treatment and purification of waters of this class constitute one of the most difficult problems which can be set before the waterworks engineer and chemist. If, in addition, the site of the supply is tropical, provision must be made to allow of alteration of method according to seasonal fluctuation in quality. The maximum of impurity to be dealt with is far in excess of the mean, and in devising the process and designing the plant this condition must be held steadily in view. The Authors have had the advantage of closely studying methods devised and put into use by one of them at the Mare aux Vacoas Waterworks in Mauritius, and for the last 10 years they have from time to time endeavoured to improve the process both in principle and in detail. The methods adopted, and their general adaptability to similar waters, can best be understood after consideration of the situation and history of the Mare aux Vacoas.

The Mare aux Vacoas, Mauritius.—This lake was originally a morass surrounded by semi-tropical forest. It had a comparatively small area and depth, and was fed by numerous streams coming from a wooded district. The surplus water flowed into the Tamarind River. The area of the lake was increased by the construction of a dam, and the enlarged area was never cleared, the trees and scrub being immersed and ultimately dying and decaying. On account of the immersed and decaying vegetable matter, considerable difficulty has been experienced in purifying the water to a satisfactory point. The difficulty was increased by the fact that a large population was dependent on the water of the Mare aux Vacoas, and therefore the supply could not be suspended even for a short time.

The method of improvement adopted by one of the Authors was as follows :—In the first place the water-level was lowered to the greatest extent compatible with the maintenance of the supply, and a contoured survey of the lake was made. The banks were cleared of trees and vegetation of all kinds to low-water line, and up to about 10 feet above high-water. The " voons " (a water-plant) were cut as close to the bottom as possible, and their roots and the stumps of " vacoas " (screw-pines) were torn up by a steam grab-dredger.

According to the scheme originally devised, the sill of the sluice for compensation-water and that for the supply were at about bottom water-level (or zero of the Mare gauge). Thus the water for consumption was drawn from the lowest and most contaminated stratum. The compensation-sluice, though properly placed as regards depth, was so small that it could not discharge enough water even in a moderate flood ; and the pure incoming rain-water poured over the Tamarind dam instead of displacing the contaminated water and being itself retained. The defect was remedied by constructing a large sluice in solid ground on the north flank of the Tamarind dam, 10 feet wide, with its sill 1 foot below the zero of the Mare aux Vacoas gauge, and closed by a Stoney sluice.

All compensation-water is therefore now drawn from the lowes strata of the reservoir, and the area of waterway is sufficient t discharge the surplus water in all but extraordinary floods. By raising the sluice the dam may be prevented from overflowin during normal wet weather, and surplus water escapes from th lowest strata of the reservoir, not from the surface as before. A new outlet, in the form of a circular chamber provided with sluices arranged in steps, so that the supply could always be taken off within 1 foot of the surface, was constructed at the north end of the reservoir. Passages were formed for the principal streams feeding the Mare, and all shallow areas of contaminated marshy water were banked off. A depositing-reservoir, with a capacity of 1,000,000 gallons, and four filter-beds, each having an effective area of 7,200 square feet, were constructed below the Mare. These works, which were carried out under the direction of Mr. E. A. Brine, Assoc. M. Inst. C.E., as Resident Engineer, assisted by Mr. Paul le Juge de Segrais, Assoc. M. Inst. C.E., produced a marked result. The water, which at first was hardly filterable, became so under normal conditions. In dry seasons, however, grave inconvenience was experienced. The water which, though slightly coloured and turbid, was not objectionable or undrinkable before filtration, developed after filtration an offensive fishy smell. On this account recourse was had to a chemical method of purification.

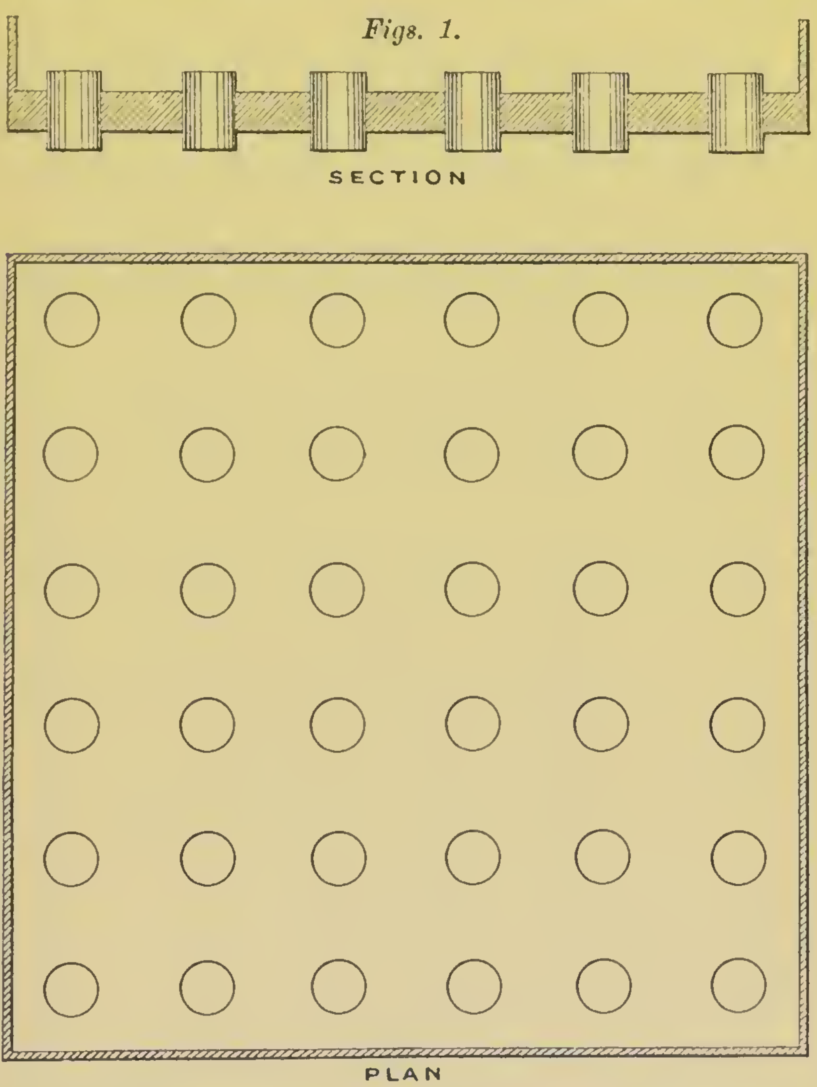
Preliminary trials had shown that the water could be materially improved by agitation with iron. Further experiments established that the water could be brought to a satisfactory condition by treatment by the Anderson process, if it were afterwards adequately aerated. Many other processes were tried, but were not equally successful. The improvement of the water after treatment with iron is shown by the following analyses:—

——	Untreated Water (1892).	Untreated Water (1901).	Treated Water.
	Grains per Gallon.	Grains per Gallon.	Grains pe Gallon.
Total solids	6·91	5·32	..
Chlorine	0·98	1·27	..
	Parts per 100,000.	Parts per 100,000.	Parts per 100,000.
Free ammonia	0·029	0·002	0·029
Albuminoid ammonia	0·031	0·064	0·006
Oxygen absorbed	0·43	0·42	0·10
Nitrogen as nitrites	Nil	Nil.	..
,, ,, nitrates	Trace	Nil.	..
Hardness	1·5°	2·5°	..

Owing to the fact that this water contains a large quantity of organic matter, the amount of iron necessary for its purification is large; and the precipitation of this iron can be accomplished only if the water is thoroughly aerated after passing through the Anderson apparatus. The usual method of allowing the water to fall over terraces or cascades is not sufficient; the area thus exposed is too small to ensure that the water shall be saturated with air.

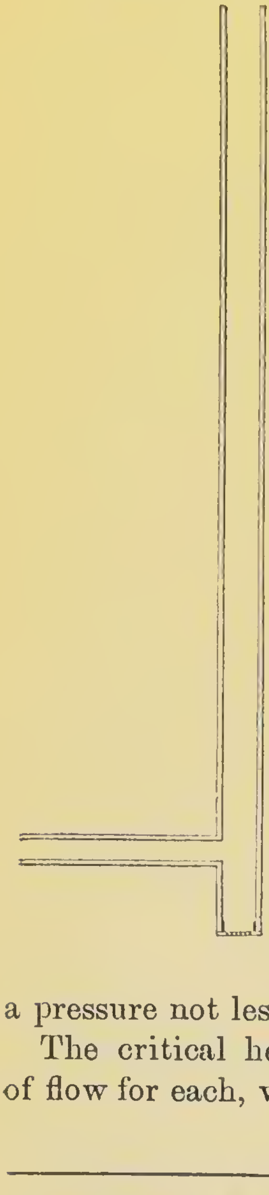
Experiments on Aeration.—In order to increase the area exposed various devices were tried. These included the use of plates with holes having a raised margin, as shown in *Fig. 1*, and of such a diameter (*e.g.* ½ inch) that the water flowing over the margin fell in isolated drops; the principle of the Lunge plate-tower (*Figs. 7*) was also used experimentally. But these methods did not promise a successful result. The quantity of water that could be treated

Figs. 1.



with a given area of plate was too small; and it was found difficult to adjust the level of a large number of orifices so exactly as to ensure an equal flow through each. After many experiments the simple device of allowing the water to issue in thin cylindrical streams, thus exposing a surface relatively large, was adopted. It was found by trials made with glass tubes closed at the lower end by a perforated plate, as shown in *Fig. 2*, that when the water flowed through the holes under a small head, *e.g.*, 2 or 3 inches, the issuing jets from adjacent holes coalesced in a thick, rope-like stream, thus presenting a greatly reduced surface for absorption of oxygen. Naturally this was more likely to occur the more closely the holes were pitched. As it was desired that the aerating apparatus should be compact, it was necessary that the pitch should be moderate; and yet the streams of water must not run together. Further trial showed that, for a given size of orifice, there was a certain critical head below which the streams would coalesce if by chance they touched each other. At and above the critical head, the streams separated spontaneously, even if they were intentionally caused to touch for a moment. It follows that the proper working of an apparatus made on this principle, and discharging jets in the open air, will be only temporarily disturbed by a gust of wind or other cause which may deflect the streams, provided that the water is being discharged at a pressure not less than the critical head.

Fig. 2.

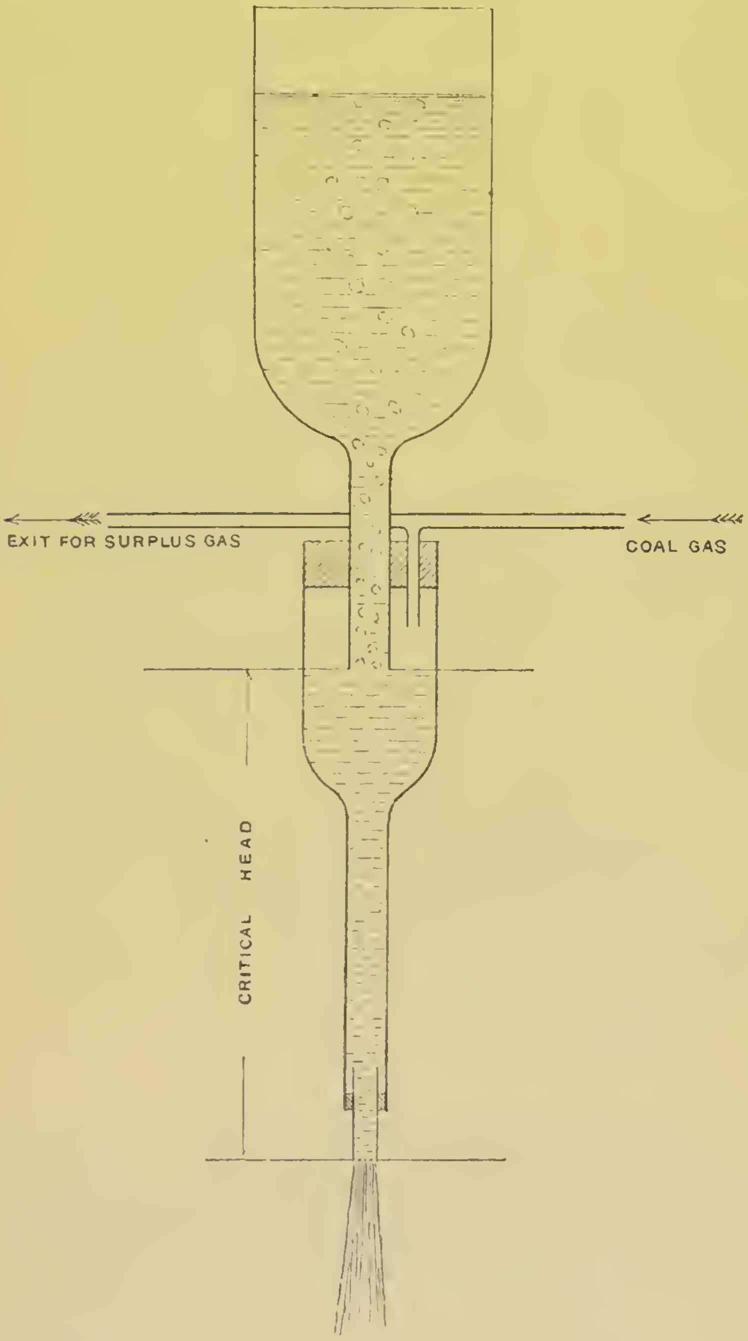


The critical head for holes of various diameters, and the rate of flow for each, were determined, with the following results:—

Size of Hole.	Diameter.	Critical Head.	Rate of Flow per Hole under critical Head.
S.W.G.	Inch.	Inches.	Gallon per Hour.
No. 19	0·040	8	0·87
„ 20	0·036	11	0·83
„ 21	0·032	12	0·67
„ 22	0·028	16	0·52
„ 23	0·024	22	0·52

It was also necessary to decide what size of hole and what fall were requisite, in order to aerate the water thoroughly. Accordingly, water which had been freed from dissolved air was allowed to flow through perforated plates fixed in the experimental

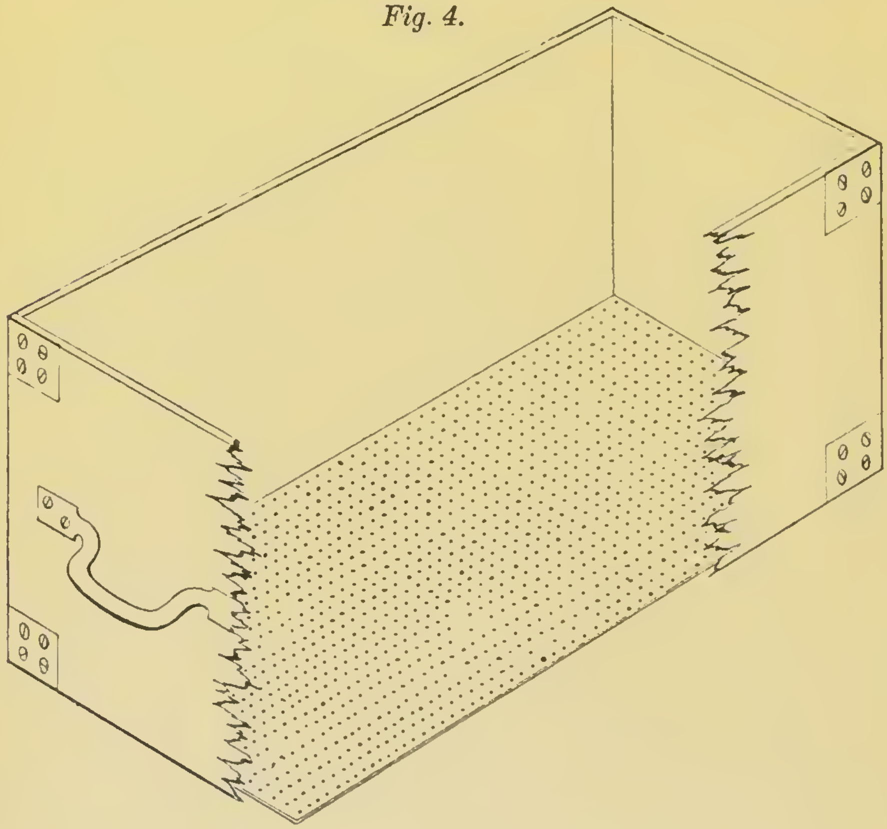
Fig. 3.



apparatus shown in *Fig. 3*: the air-free water was protected from premature contact with air by being surrounded with an atmosphere of coal-gas. After falling through the prescribed distance, it was caught, and the quantity of oxygen which it had absorbed during its fall was determined. The results showed that absorption was practically complete in a fall of 6 feet, the water being then nearly saturated with oxygen. It was also found that although, as might be expected, the smaller jets were somewhat more rapid in their aerating effect, yet a comparatively coarse jet, *e.g.*, 0·04 inch in diameter, was quite efficient. For practical reasons a fairly large orifice is preferable, as it is less liable to be choked by fine suspended particles which may be contained in the water.

Aeration Apparatus.—These experimental results took working shape in the following way:—A number of trays or drawers, 2 feet by 1 foot by 1 foot, were made of teak, the bottom of each consisting of a delta-metal plate $\frac{1}{8}$ inch thick and pierced with numerous orifices pitched $\frac{1}{4}$ inch apart (*Fig. 4*). There were thus 4,584 orifices in each drawer, discharging collectively 3,988 gallons per hour. In all, fifteen drawers were provided, capable of handling 1,000,000 gallons per 24 hours, proper allowance being made for some being out of use for cleaning during that time. Each tray could be removed, turned on end, and cleaned with a hose or brush without interfering with

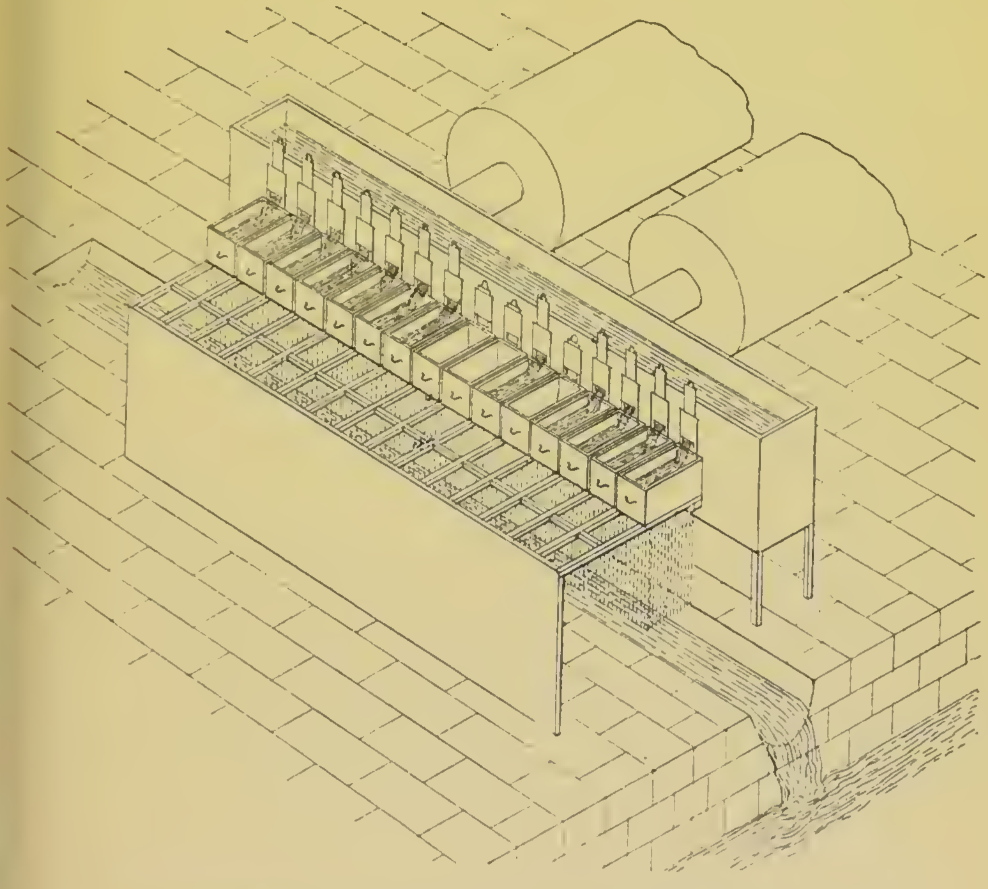
Fig. 4.



the working of the rest of the apparatus. The water to be aerated, after passing from the Anderson revolving purifier, was allowed to flow into a distributing-trough and thence through small sluices into the boxes. The arrangement of the whole apparatus is shown in *Fig. 5.* The opening of each sluice could be adjusted so that the box beneath it was kept filled to or slightly above the critical head of 8 inches.

The result of the treatment with iron by the Anderson process, followed by the special method of systematic aeration employed, has been to make the water filterable at all seasons of the year.[1] The filtrate is free from the disagreeable taste and smell which formerly made it unfit for drinking and domestic use. The use of iron as a precipitant is unquestionably valuable, but its value

Fig. 5.



Arrangement of Aeration Apparatus at Mauritius.

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[1] Some difficulty was experienced in the season 1899–1900 when a serious drought occurred and the water was exceptionally impure; at that time, however, the supply of air to the revolving purifier was inadequate. This has since been remedied, and in 1901 and 1902 no trouble arose.

would not be effectively attained if it were not aided by thorough aeration. The function of the oxygen imparted to the water by the aerating apparatus is two-fold; first, to oxidise the ferrous compounds and to induce precipitation of a great part of the organic matter by the ferric hydroxide resulting from this oxidation; secondly, to destroy residual organic matter during the passage of the water through the filters. The great importance of this second stage is proved by observations made in Mauritius by Mr. le Juge de Segrais on the effect of intermittent filtration. Before the present apparatus was fully at work, he found that in the dry season, when the water was loaded with organic matter, it acquired a fishy taste and smell during its passage through the filters. He also found that this could be prevented, and a good filtrate could be obtained, if the filters were worked intermittently, allowing ample time for their aeration. In Mauritius local conditions forbade the adoption of this simple method; but it is noteworthy as emphasizing the advantage of copious and controlled addition of oxygen to a water loaded with organic matter difficult of removal. When the cost of construction of spacious filter-beds is not prohibitive, this particular method of oxygenation may be applied with good effect. A case in point is that of the waterworks at Singapore, where an excellent system of intermittent filtration has been elaborated by Mr. S. Tomlinson, M. Inst. C.E., late Municipal Engineer of the town. Being confronted with a difficulty similar to that which was encountered in Mauritius, Mr. Tomlinson found that he could prevent the occurrence of the fishy smell and taste of the water by working filters at such intervals as to allow of their aeration. Mr. Tomlinson has been kind enough to communicate to the Authors his experience in this matter, and the result of his observations is given in Appendix IV. (p. 44).

PURIFICATION OF WATER FROM NAIROBI RIVER, UGANDA.

The process devised for Mauritius was put to work and proved successful. In consequence, the principle was applied in a case of even greater difficulty. The water of the Nairobi River in Uganda is considerably worse than that of the Mare aux Vacoas in Mauritius. The analyses on p. 33 are sufficiently illustrative.

So impure a water is quite unfit for drinking, and requires elaborate methods of purification. Many experiments were tried, and finally the following process was selected:—The water is passed through an Anderson revolving purifier of ample size, and is there treated with a large volume of air. By this treatment it

UGANDA (NAIROBI RIVER).

—	1	2	3
	Grains per Gallon.	Grains per Gallon.	Grains per Gallon.
Total solids	20·86	23·83	13·58
Chlorine	2·37	2·37	1·73
	Parts per 100,000.	Parts per 100,000.	Parts per 100,000.
Free ammonia	0·008	0·004	0·020
Albuminoid ammonia	0·044	0·060	0·020
Oxygen absorbed (4 hours)	1·22	1·14	0·20
Nitrogen as nitrites	Nil	Nil	Nil
,, ,, nitrates	..	..	..
Hardness	..	..	3·50

is caused to dissolve a considerable quantity of iron. The ferruginous water is aerated by passage through a series of trays precisely similar to those employed in Mauritius, except that they are made of galvanized iron, wood being attacked by the white ant. The aerated water flows into settling-tanks and there deposits the bulk of the dissolved iron. Complete purification, however, is not accomplished by this single treatment, which suffices for the Mauritius water.

A certain amount of the organic matter, and probably even some of the iron, remains in solution and must be removed. This is done by precipitation in a second set of tanks with a small quantity (about 1 grain per gallon) of aluminium sulphate and its equivalent of lime. The precipitate is allowed to settle, and the fairly clear water is finally filtered through a "Torrent" filter. *Figs. 6* illustrate the essential parts of the plant. The improvement effected by this treatment is shown by the following analyses :—

ANALYSES OF SAMPLE OF WATER FROM NAIROBI RIVER.

Before Purification.

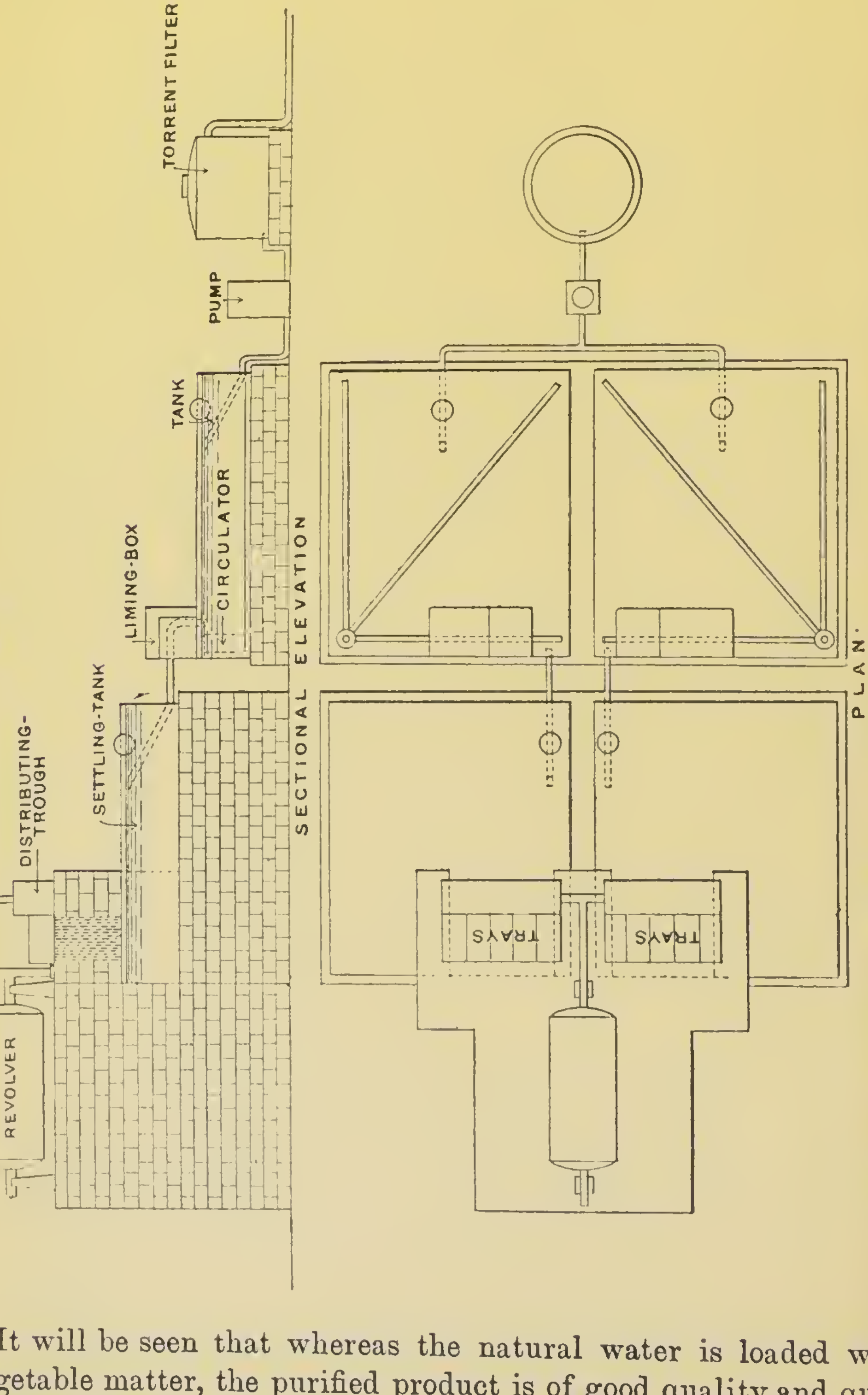
	Grains per Gallon.
Total solids	13·58
Chlorine	1·73
	Parts per 100,000.
Free ammonia	0·020
Albuminoid ammonia	0·020
Oxygen absorbed (after 4 hours)	0·20
Nitrogen as nitrites	Nil
,, ,, nitrates	Nil

Hardness, 3·5°.

After Purification.

	Parts per 100,000.
Free ammonia	0·112
Albuminoid ammonia	0·004
Oxygen absorbed (after 4 hours)	0·010

Figs 6.



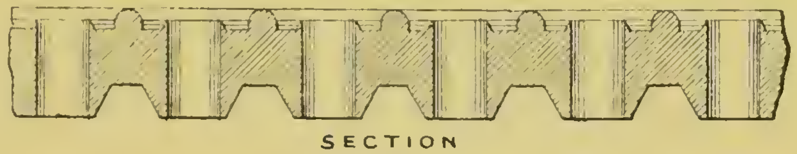
PURIFICATION-PLANT FOR WATER FROM THE NAIROBI RIVER, UGANDA.

It will be seen that whereas the natural water is loaded with vegetable matter, the purified product is of good quality and quite potable.

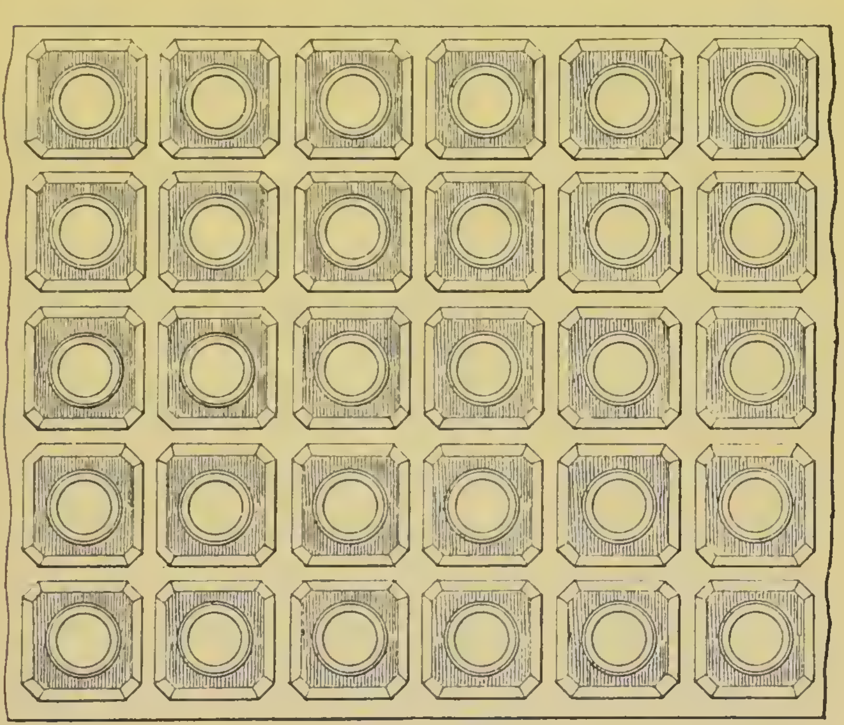
Possible Applications of the Aerating Process.

The foregoing method of aerating water in an effective manner by exposing slender jets to the air is, as far as the Authors know, novel. Its utility has been proved for the oxidation of waters containing iron artificially added. Obviously it will serve for the treatment of ferruginous water, and for this purpose it has been already adopted. There are other purposes for which it may prove to be useful. For example, in the treatment of sewage by the action of aerobic bacteria, oxygen necessary for the healthy life of the organisms is administered by intermittent filtration, the beds being emptied at intervals, and thus aerated. Various sprinkling devices are also adopted, both to distribute the sewage over the contact-beds, and incidentally to aerate it to some extent. It appears to the Authors probable that the necessary aeration may be more effectively attained if the sewage, freed from grosser particles of suspended matter, is caused to flow in thin

Figs. 7.



SECTION



PLAN

Lunge Plate.

individual streams through a perforated plate under a critical head. The holes, if as small as those used by the Authors for the treatment of water, may become choked too readily, and a somewhat larger size may be requisite; in any case, however, the trays are so easily removed and cleaned without stopping the working of the apparatus as a whole, that the difficulty is not likely to be serious unless the previous subsidence and screening of the sewage should prove to be impracticable.

Another suggested application is for the cooling of condenser-water. Where there is no space available for a cooling-pond it is usual to pump the hot water from the condenser over a pile of brushwood or similar arrangement, so that the water may be cooled by its own evaporation. Evidently this somewhat crude and cumbrous apparatus might be replaced by a set of perforated plates with a considerable saving of space and increased efficiency of working.

The primary purpose for which the apparatus was devised was the treatment of water with air; obviously it is suitable for the treatment of liquids with gases generally; such operations are frequently needed in chemical industry. Conversely it is fitted to treat gases with liquids, *i.e.* to act as a scrubber. In many chemical manufactures the old coke scrubber has been advantageously replaced by the Lunge plate-tower, which consists of a series of plates, each provided with perforations about ½ inch in diameter, and having a rim or collar, so that the liquid with which the gas is to be treated flows slowly and regularly over this lip, and drips down (*Figs. 7*). This apparatus has proved of great utility, but the Authors venture to think that in some instances, at least, the use of the finely-perforated plates described in this Paper, working under a critical head, may be found preferable.

This and the foregoing suggestions are merely mentioned as fairly obvious applications of the principle which has been described. Each would require detailed study before a working apparatus was devised. For the treatment of impure water, however, of the class which forms the subject of this Paper, the method is no longer in a tentative stage; it has justified itself by the test of practical utility.

The Paper is accompanied by seven drawings, from which the Figures in the text have been prepared, and by the following Appendixes.

[APPENDIXES.

APPENDIXES.

APPENDIX I.

A group of analyses of water from Antigua may be quoted in further illustration of the great influence of delay in flow, or of actual stagnation, on the amount of the degradation products of vegetable matter acquired by tropical waters.

ANTIGUA.

—	1 Water from Filter-Beds at Grays Hill before Filtration (mainly Spring-water, not Stagnant).	2 Water from Boddy Ponds; dry Season (Semi-stagnant).	3 Water from Middle of Reservoir Wallings; (Stagnant). Unfiltered.	4 Water from Middle of Reservoir Wallings; (Stagnant). Filtered.
	Grains per Gallon.	Grains per Gallon.	Grains per Gallon.	Grains per Gallon.
Total solids	33·32	46·34	22·12	21·21
Chlorine	5·38	12·19	2·40	2·40
	Parts per 100,000.	Parts per 100,000.	Parts per 100,000.	Parts per 100,000.
Free ammonia	0·003	0·005	0·004	0·003
Albuminoid ammonia	0·005	0·009	0·017	0·015
Oxygen absorbed (after 4 hours)	0·10	0·16	0·24	0·22
Nitrogen as nitrites	Nil	Nil	Nil	Nil
,, ,, nitrates	Nil	Nil	Trace	Trace
Hardness	9·5°	11°	4°	4°

It will be seen that the stagnant condition of the third sample has caused it to acquire an amount of vegetable pollution which is not only relatively large, but is evidently difficult of removal by ordinary filtration. It is this difficulty of removal which is so serious a matter in the selection and purification of a tropical water-supply.

The facts set forth above receive corroboration from a large number of analyses which the Authors have been led to make from time to time of waters from various tropical regions. Some of the more interesting of these, from African sources, are recorded in the Tables on pp. 36–39, namely, samples from Cape Coast Castle, Accra and the Victoria Nyanza.

Sweet River is a perennial stream about 30 feet wide at the point where the samples were taken, coming down from a country covered with dense bush and scrub. Although the river itself is fairly swift, it forms large pools at intervals, and in these the flow is naturally sluggish. Such conditions go far to account for the presence of the relatively large amount of vegetable contamination in all the samples disclosed by the analysis. The water as it stands cannot be considered potable, but it must not be concluded that a potable supply is

CAPE COAST CASTLE.

Sweet River.

—	Taken during Rainy Season.					Taken during Dry Season.			
	1	2	3	4	5 Pool with little Current.	6	7	8	9
	Grains per Gallon.	Grains per Gallon.	Grains per Gallon.	Grains per Gallon.	Grains per Gallon.	Grains per Gallon.	Grains per Gallon.	Grains per Gallon.	Grains per Gallon.
Total solids . . .	9·94	13·30	6·16	6·30	6·86	10·08	11·76	13·16	11·62
Chlorine	1·13	1·14	0·86	0·86	0·77	2·55	4·16	3·08	3·22
	Parts per 100,000.	Parts per 100,000.	Parts per 100,000.	Parts per 100,000.	Parts per 100,000.	Parts per 100,000.	Parts per 100,000.	Parts per 100,000.	Parts per 100,000.
Free ammonia . .	0·036	0·026	Nil	0·002	0·034	0·040	0·100	0·120	0·020
Albuminoid ammonia	0·061	0·108	0·032	0·028	0·038	0·200	0·040	0·020	0·020
Oxygen absorbed .	1·33	1·82	0·66	0·64	0·69	0·71	0·74	0·72	0·47
Nitrogen as nitrites	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
,, ,, nitrates	,,	,,	Trace	Trace	Trace	,,	,,	,,	,,
Hardness . . .	4·0°	3·0°	2·5°	2·0°	2·5°	3·0°	3·0°	2·5°	3·0°

ACCRA.

Various rivers and springs.

—	1 Insuasi River (clear running Stream).	2 Spring.	3 Spring.	4 Pool near Iheem (near Marsh).	5 Papoo Stream.	6 Papoo Stream.	7 Adjamenta Stream.	8 Adjamenta Stream.	9 Adjamenta Stream.	10 Iheem Stream.
	Grains per Gallon.	Grains per Gallon.	Grains per Gallon.	Grains per Gallon.	Grains per Gallon.	Grains per Gallon.	Grains per Gallon.	Grains per Gallon.	Grains per Gallon.	Grains per Gallon.
Total solids	13·16	7·98	6·16	17·08	14·00	14·84	10·78	10·64	10·78	17·78
Chlorine	3·26	2·78	1·92	4·70	2·22	2·42	2·42	2·18	1·84	3·67
	Parts per 100,000.	Parts per 100,000.	Parts per 100,000.	Parts per 100,000.	Parts per 100,000.	Parts per 100,000.	Parts per 100,000.	Parts per 100,000.	Parts per 100,000.	Parts per 100,000.
Free ammonia	0·002	0·004	0·002	0·056	0·003	Trace	0·001	Trace	Nil	Trace
Albuminoid ammonia . .	0·008	0·010	0·008	0·030	0·026	0·013	0·023	0·027	0·035	0·050
Oxygen absorbed . . .	0·18	0·08	0·04	0·47	0·74	0·15	0·60	0·36	0·57	0·75
Nitrogen as nitrites . . .	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
,, ,, nitrates . .	0·36	,,	,,	,,	,,	,,	,,	,,	,,	,,
Hardness	3·5°	2·0°	3·0°	8·0°	2·75°	3·0°	2·5°	1·5°	2·0°	2·5°

UGANDA.

Various Springs, Rivers and Lakes.

—	River Molo.	Nairobi River.	Nairobi River.	Nairobi River.	River Athi.	Lake Nakuro.	Spring near Lake Nakuro.	Springs near Ziwani.
	Grains per Gallon.	Grains per Gallon.	Grains per Gallon.	Grains per Gallon.	Grains per Gallon.	Grains per Gallon.	Grains per Gallon.	Grains per Gallon.
Total solids	12·46	20·86	23·83	13·58	17·64	257·46	25·90	13·02
Chlorine	0·76	2·37	2·37	1·73	2·02	31·92	1·14	2·02
	Parts per 100,000.	Parts per 100,000.	Parts per 100,000.	Parts per 100,000.	Parts per 100,000.	Parts per 100,000.	Parts per 100,000.	Parts per 100,000.
Free ammonia	Nil	0·008	0·004	0·020	0·016	0·094	Trace	0 032
Albuminoid ammonia . . .	0·030	0·044	0·060	0·020	0·036	0·028	0·006	0·028
Oxygen absorbed (4 hours) .	0·55	1·22	1·14	0·20	0·85	2·25	0·15	0·10
Nitrogen as nitrites	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
,, ,, nitrates . . .	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
Hardness	..	..	..	3·5°	3·5°	..	..	3°

unprocurable from this source. A great improvement can doubtless be effected by clearing the margins of the springs and watercourses, and by so straightening and deepening the channels that the water is no longer imprisoned in stagnant pools exposed to the débris of all sorts of extinct vegetable life. It is not the abundance of tropical vegetable life in itself which is harmful, but its rapidity of decay, and the opportunity for the absorption of the products of this decay, which affect injuriously the purity of the water.

The gathering-ground of the Adjamenta stream, Accra, is a valley about 900 feet above sea-level, about 6 miles long, and having an average width of 1½ mile. Numerous tributaries feed the main stream, which leaves the valley by a narrow neck and passes over a series of falls. The water in its present condition cannot be pronounced good, but in this instance the causes are local rather than general. Various native villages and palm-oil factories contribute a good deal of contaminating matter, but it is probable that some at least is derived from the presence of stagnant pools and marshy places on the main stream and its tributaries.

VICTORIA NYANZA.

	Grains per Gallon.
Total solids	16·38
Chlorine	0·86
	Parts per 100,000.
Free ammonia	0·026
Albuminoid ammonia	0·130
Oxygen absorbed (after 4 hours)	0·61
Nitrogen as nitrites	Nil
,, ,, nitrates	Nil

Hardness, 3°.

Mineral Analysis.

	Grains per Gallon.
Silica (SiO_2)	0·71
Oxide of iron and Alumina ($Fe_2O_3 + Al_2O_3$)	0·18
Lime (CaO)	0·91
Magnesia (MgO)	0·79
Soda (Na_2O)	3·16
Carbon dioxide (CO_2)	2·88
Sulphur trioxide (SO_3)	0·15
Chlorine (Cl)	0·86
	9·64
Oxygen for Chlorine	0·19
	9·45
Water, etc.	6·93
Total solids	16·38

Chief Salts.

	Grains per Gallon.
Calcium carbonate ($CaCO_3$)	1·62
Magnesium carbonate ($MgCO_3$)	1·66
Sodium carbonate (Na_2CO_3)	3·13
Sodium sulphate (Na_2SO_4)	0·27
Sodium chloride ($NaCl$)	1·42

The water last cited is noteworthy chiefly on account of its origin. The Authors are not aware that any previous analysis of the water of Victoria Nyanza has been published, and they thought the matter of sufficient interest to give a complete analysis of the mineral constituents as well as the ordinary organic data. For so huge a body of water, which could hardly be supposed to be influenced by any ordinary source of contamination, the water is remarkably impure. The Authors have no means of ascertaining from what portion of the lake or how far from shore this sample was taken. In the absence of this information it would be rash to assume that this highly polluted water is an average sample of the lake generally; but, however this may be, it is certainly remarkable that a source of supply which might naturally be regarded as unexceptionable can be, at least in parts, objectionably impure.

APPENDIX II.

Pond at Rowledge.

This pond is situated on the border of a large wood, in a shallow depression, with no perceptible incoming stream, and with sides sloping so gently that the rain collected by them flows but slowly into the pond. It is surrounded with vegetation growing freely and in quantity, and on the margin are a good many trees. The fields, which come down to the water's edge, bear grass abundantly, and there is a profusion of small, moisture-loving plants on the very edge, these being sometimes immersed when the pond is full. In the summer there is a rapid growth of true aquatic plants, spreading far out from the shore, and in places completely hiding the surface of the water. As the season passes, a part of these water-plants may be stranded by the shrinkage of the pond, and die prematurely in consequence; ultimately the whole crop perishes in the ordinary course of its life history. Thus there is left a large quantity of non-woody vegetable matter, slender stalks, and delicate leaves, rapidly rotting. The falling foliage of the trees on the margin contributes to the mass of decaying material finding its way into the waters of the pond. All these phenomena are at their height after a period of hot dry weather, and it was at the end of such a period that the sample was taken of which an analysis is given in the Paper.

APPENDIX III.

Description of the Mare aux Vacoas.

The Mare aux Vacoas (Marsh of screw-pines *Pandanus Vacoas* or *P. Sativa*) is situated in the central plateau of Mauritius at an elevation of about 1800 feet above sea-level.

When one of the Authors first saw it in 1891, it had already been converted into a storage-reservoir by the construction of a dam, about 7 feet high and 420 feet long, across its principal outlet to the Tamarind River, thus making a shallow reservoir, having an area of 237 acres. The gathering-ground of the Mare aux Vacoas has an area of about 5 square miles, all now Government forest reserve, uncultivated and uninhabited. The only large animals on the gathering-ground are a few sambur deer. The water collected in the Mare reservoir is therefore above suspicion as regards sewage contamination. The gathering-ground is covered with bush, with occasional trees of considerable size.

The average rainfall is about 130 inches, well distributed throughout the year. Indeed, a wholly rainless month is unusual, and for about 8 months in the year a wholly rainless day is almost an exceptional circumstance. During the cyclone season, January to March, very heavy downpours occur.

The gathering-ground leaves nothing to be desired as to freedom from pollution, and the occurrence of a natural marsh and lake proves the existence of an impervious bottom. Thus, many important conditions for the construction of an impounding-reservoir and for the provision of an ample and good water-supply were present. The drawback to the Mare aux Vacoas as a reservoir-site was its flatness, and the gently sloping character of its margin, which rendered it impracticable to make a fairly deep reservoir, except perhaps at a prohibitory cost. Unfortunately, the site was not cleared of vegetation. The whole of the land submerged was left absolutely untouched.

When one of the Authors first saw the Mare aux Vacoas, it presented the appearance of a green meadow. Standing on an eminence, at the western extremity of the reservoir and looking eastward, this green plain was visible, with a small patch of dark water in its midst, probably the deep part which formed the natural lake already referred to. In the middle distance there was a large clump of forest trees killed by the submergence of their roots, and rotting as they stood in the water. At the eastern extremity, there was a flat tract covered with tussock-grass and low bushes partially submerged, but the bushes were not yet killed.

The water was of a brown peaty colour. Viewed in the 2-foot tube, it was nearly opaque, and of a dark brown, almost porter-like colour. An experimental sand-filter 6 feet square was made. The water proved to be practically unfilterable by the ordinary process of sand filtration, the sand becoming choked with glutinous matter in a few hours. Agitation with metallic iron produced a marvellous change. A marked brown precipitate was deposited. The decanted water was filterable, and the water, when seen through a 2-foot tube, was clear, and only slightly yellow in colour. Laboratory experiments subsequently made confirmed this observation and formed the basis of the method of purification described in the Paper.

The vegetation which invaded the water space consisted practically of one plant only, that known locally as "Voon." The botanical name of this plant is *Eleocharis*. It is a rush-like plant, having a creeping root-stalk firmly anchored to the bottom by rootlets. From this, long green shoots sprout and grow upward until their tips protrude about 12 to 18 inches above the water-level, when a small brush-like flower, of a brown colour, is developed, at the apex of the shoot. The shoot is devoid of leaves, it is smooth and cylindrical, about 3-16ths inch in diameter, hollow, with thin walls, and is divided into separate cells by diaphragms. When growing, these cells are entirely free from water, even at the greatest depths. When the voon shoot has reached maturity, and put forth its flower, it becomes water-logged and sinks to the bottom, where it slowly decays. Fresh shoots are then thrown off, penetrate the tangle of decaying shoots, and reach the surface. This growth and decay goes on perennially; so that in the natural state, there is a constant field of green voon densely packed below with a tangled mass of dead and decaying shoots. The maximum depth of water in which voon can grow appears to be about 10 feet.

In the Authors' belief, it is to the decay of voon that the strong impregnation of vegetable matter is due. The bed of peat-like matter on the bed of th reservoir, the product of ages of decomposition also, no doubt, contributes largel to the contamination, as well as the roots and stumps of Vacoas and other plant killed by submergence.

APPENDIX IV.

PURIFICATION OF THE WATER-SUPPLY OF SINGAPORE.

Mr. S. Tomlinson, late Municipal Engineer of Singapore, has kindly communicated the results of his experience with the water-supply of that city. Th water at Singapore occasionally possesses an objectionable smell, recalling tha of sulphuretted hydrogen. The method adopted for removing this consist substantially of intermittent filtration. No special effort is made to aerate th water, but it happens that the pipes delivering into the well feeding the filter are turned upward, so that as the water flows in it is considerably agitated i contact with air.

From the well the water flows into the filters in the ordinary way. Thes are worked as usual in all respects, except that they are emptied and refille fairly frequently, *i.e.*, every 4 to 14 days according to the season ; the sand-bed i aerated for about 12 hours between the time of emptying and refilling. The rat of filtration is about 20 gallons per square foot per 24 hours, the time bein that during which the filter is actually running. By this method it has prove possible to obtain regularly a satisfactory filtrate, even when the raw water i more than ordinarily impure.

Discussion.

The President. The **President**, in moving a vote of thanks to the Authors, remarked that the Papers dealt with questions of great practical importance, and he was assured by friends who were experienced in such matters that they were likely to be of considerable value to future engineering practice in water-supply.

Prof. Brown. Professor **Campbell Brown** placed on the table a typical specimen of what he called "limpets," and some called "barnacles," but which were really incrustations of iron. The incrustation was the colour of iron rust, but it had been quite black when fresh. He also exhibited a specimen of iron pipe with some of the incrustations still intact, showing the softness of the metal for some distance from the inner surface. The specimen seemed to be bright the whole way through, but that appearance was deceptive; when it was fresh the difference in the shade could be seen nearly half-way in. In spite of the apparent similarity in the colour and consistency a knife would cut into the inner surface, but not into the outer surface.

With regard to the Paper by Messrs. Chadwick and Blount, he would like to ask what quantity of iron was employed relatively to the quantity of water. Also, to call attention to the fact that oxygen dissolved in water with great rapidity, not to an extent of more than 6 cubic centimetres per litre in the case of atmospheric oxygen, but very rapidly; and therefore the chief use of the elaborate aerating apparatus was not really to get the water saturated with oxygen. There was confirmation of this view in the statement in the Paper that there was no advantage in making the orifice or the sectional area of the jet small. It would probably be found that the object accomplished by the apparatus lay in the oxidation of the impurities and not in the aeration of the water. A microscopic examination of the surface of the aerating apparatus after use might be useful. Presumably the action of the iron was somewhat as follows:—The iron dissolved, and formed a ferrous salt in solution; then the ferrous salt was oxidized and formed an insoluble basic ferric salt, carrying the impurities with it when allowed to settle, or when filtered.

Mr. Chadwick. Mr. **Chadwick** exhibited a number of lantern slides illustrating the work carried out in Mauritius.

Mr. Blount. Mr. **Blount** mentioned that whatever merit there might be in

Mr. Blount. the device of aerating water by allowing it to flow forth i
thin streams was due to Mr. Chadwick, with whom he had ha
the advantage of working out the process.

Mr. Mansergh. Mr. JAMES MANSERGH, Past-President, thought that, in saying i
his Paper that it was unwise to remove the incrustation in iro
pipes by scraping in the usual way with the hydraulic scraper
Professor Campbell Brown had not quite appreciated the force of th
objection to the deposit. In considering the matter the enginee
was on the horns of a dilemma. The Author had said that if th
pipe was scraped, its life was shortened; but if the pipe was no
scraped its life was also shortened, because the pipe might be s
incrusted that it would not convey one-fifth of the intende
quantity of water. With regard to deposits of carbonate of lime
he had placed on the table a piece of pipe taken from one of th
Bath mains about 30 years ago. The bore of that pipe was abou
two-thirds choked with a deposit of what was practically pur
carbonate of lime, there being with it only a trace of magnesia
but the pipe itself was perfectly sound. In the slime-deposits h
had been greatly interested for some time. It was no secret no
that the Liverpool Corporation had been very much exercised i
their minds a few years ago, on finding that the discharging
capacity of their main between the reservoir at Vyrnwy and th
filter-beds at Oswestry had materially diminished—he believed b
as much as 20 to 25 per cent. Below the filter-beds, howeve
practically no diminution of discharging-capacity had occurre
After investigation of the matter by the Corporation's engineer
Mr. Deacon had suggested that the deposit above Oswestry shoul
be removed by revolving brushes, and that had been done wit
considerable success. About that time Mr. Mansergh had had t
lay two lines of large pipes, each 37 miles in length, for Birmin
ham; and it had been a matter of great importance that th
experience of Liverpool should not be repeated. He had therefo
obtained the authority of the Waterworks Committee of Birmin
ham to consult Mr. Parry, the Engineer of the Liverpool Wate
works, Professor Campbell Brown, and Professor Rubert Boyc
who had willingly given him all the information they possess
on the subject; and he was now taking measures which
hoped would prevent that deposit, so that there might not
any necessity in the future to remedy it. Put in untechnic
language, the substance of the information he had obtained wa
that there was a certain organism (*Cladothrix*) in the water whi
attached itself in large numbers to the inside of pipes, and h
the power of attracting to it as a nucleus all fine mineral or oth

Mr. Mansergh.

suspended matter in the water. The aggregations around the numberless organisms ultimately formed a united coating covering the whole surface of the pipe, which by reducing sectional area and increasing friction, diminished the effective discharge. With the Liverpool facts and the results of the experiments in his possession, and with the further knowledge that similar organisms were present in the Elan water, he had had to decide what alterations or additions it was advisable to make in the design of the works. At that time these provided for decanting the water from the higher to the lower storage-reservoir on the Elan, roughly straining it at the inlet to the aqueduct, screening it at the outlet end of the Foel Tunnel, and filtering it below the service-reservoirs near Birmingham. It had been clear that something more must be done. Accordingly, the draw-off arrangements at the intake-tower (then not absolutely settled) had been so modified as to give very delicate control of the final decantation. Further it had been decided to put in a range of filter-beds preceded by fine-gauze upward screens, competent, it was hoped, to arrest the matters which went to form the slimy deposit referred to by Professor Campbell Brown. He wished to express his acknowledgments of the courtesy and cordial co-operation of Professor Brown and his colleagues in the Liverpool investigations.

Mr. Deacon.

Mr. George F. Deacon remarked that it was important to bear in mind the distinction between the different kinds of obstruction which reduced the flow of water in iron mains. The 42-inch Vyrnwy main was put into use about 13 years ago: it had been designed to pass a certain quantity of water, and there could be no doubt as to the correctness of the calculations. An allowance of 25 per cent. had been made for nodular incrustation, which it was well known would occur in the course of 15 to 20 years. Such incrustations were familiar to every one who had had to lay iron mains in the north of England, or for almost any soft waters, and certainly for waters that had an acid reaction. But the obstruction which had given rise to Professor Campbell Brown's Paper was quite a different thing. Probably nothing would have been heard of the matter had it not been that the Vyrnwy main, which was about 68 miles long, was divided by the Oswestry filter-beds, at about one-quarter of its length from Lake Vyrnwy. Very soon after taking it into use, the portion between the lake and the filter-beds had begun to diminish in capacity, while the portion between the filter-beds and Prescot, where the principal service-reservoirs for Liverpool were, had remained practically unchanged. Although the delivery of no portion fell below that for which the

Mr. Deacon. main was calculated, the difference in the delivery of these tw portions—then about 25 per cent. higher below the filters tha above them—had naturally attracted attention, and the Liverpo Corporation had asked him to look into the matter. He ha found what he had seen in many other mains, namely, a slim coating of the interior, and, lying in the bottom of the pipe, material which looked very much like coffee-grounds when see through clear water in a white vessel. That was the dea material which Professor Brown had described, the slime bein the live material. The slime and the little pellicles of dea material in the bottom combined, had reduced the capacity of th main above the filter-beds by more than 20 per cent. The slim did its work of obstruction while adhering to the sides of th pipe in the manner described by Professor Brown; but the dea pellicles, which were heavier than water, produced a speciall harmful resistance in a totally different way, which was greatl aggravated by the fact that in the main between Lake Vyrnw and the Oswestry filter-beds, there were about twenty up-hil portions with an aggregate vertical height of about 2,300 feet. I the gradient had been everywhere downward the pellicles woul have been constantly washed out to the next reservoir; but, as i was, the water was constantly engaged in the work of Sisyphus the pellicles being just light enough to rise with the maximu velocities of flow, and just sufficiently heavy to fall back again in th momentary lull that followed. Like myriads of little marbles, thes pellicles acted as a most efficient brake, and were largely responsibl for the increased resistance to the flow of water. Chemists an bacteriologists had been called in, and Professor Brown had said a once that the deposit was not peat, and had begun to investigate i In the meantime, Mr. Deacon had devised a mechanical brush, an avoided the scraper first introduced by the late Mr. W. Froude, an constructed by Mr. Appold, which scraped the interior in such manner that any projecting portions of the nodular incrustatio were carried away. It was unnecessary for him to dwell upon th details of the brush apparatus, which he had described elsewhere Substantially, it consisted of two co-axial drums, the periphery each drum consisting of bristles of whalebone, arranged spirally such a manner that the hinder brush acted like the guides of turbine, and the forward brush like the vanes of a turbine. T water could not flow in any quantity without passing through t guides, and so actuating the vanes of the forward brush; the t

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[1] Proceedings Institution Mechanical Engineers, 1899, p. 502.

Mr. Deacon.

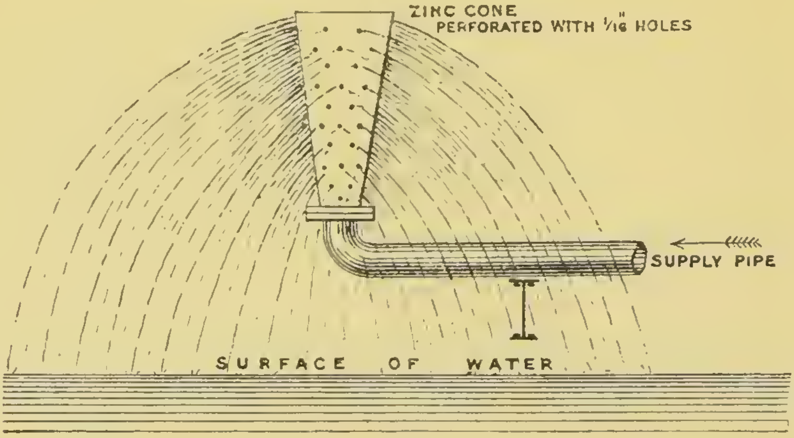
drums revolved in opposite directions. He had not felt sure that the brush would be a success on the first trial without some adjustment. It disappeared, and it was thought it must have stuck somewhere, because it could not be found at the next point at which there was ingress to the main. But, as a matter of fact, it was found within ½ an hour, several miles away; it had done its work for that portion, and had washed out practically the whole of the material, which travelled with the water a little ahead of the brush. The use of the brush had continued, and had proved a complete success, but of course its effect had been only temporary. The growth of slime and the accumulation of dead pellicles had been resumed, and the brushing had had to be repeated. Happily the brush did no harm to the interior of the pipe; the coating of asphalt was left intact, and the nodular incrustations, such as there were, had not been removed. Indeed, at that time, nodular incrustations had scarcely begun to form. It was very satisfactory to hear from Professor Brown that the slime rarely, if ever, formed in anything but acid water; but unfortunately the nodular incrustations formed in both acid and alkaline waters, though much more readily in the former. In the south of England, for example, the chalk waters showed scarcely any nodular incrustations, which he believed was principally due to the fact that carbonate of lime was deposited on the inner surface of the pipe before they had a chance of forming. He must admit that he rather agreed with Professor Brown that the use of the hydraulic scraper, as distinguished from the rotating brush, was not desirable if it could possibly be avoided. He knew many places in which it was used, and the pipes were being gradually worn away. In some places it was used every year, and in other places every two years. The process interfered with the supply; and in many cases it would be better to let the incrustations grow and form, as they certainly did, a complete protection to the iron of a main with reduced but constant delivery. This would often involve the laying of a duplicate main, which in the long run was often found to be the more economical course.

Mr. Moore.

Mr. R. St. George Moore endorsed Messrs. Chadwick and Blount's remarks as to the aeration of water in thin streams. He had been using that method on West Hampshire water for the last 6 years. The intake in the early stages had been below a water-wheel, and he had found that when the water-wheel was working, the monthly analyses were better than when the wheel was at rest. He had set to work to find a substitute for the aerating action of the water-wheel, and had devised a series of zinc cones perforated with holes

Mr. Moore. not larger than $\frac{1}{16}$-inch in diameter (*Fig. 1*), through which th
whole of the water was delivered on the filter-beds in a fine spray

Fig. 1.



and he found that the analyses were even better than they ha
been when the water-wheel was at work.

Mr. Hunter. Mr. Walter Hunter considered that Professor Brown's Pape
showed how necessary it was to treat all waters by filtratio
whether they came from mountain surfaces or from rivers; and th
fact would probably have a wide application in dealing wit
the future needs of the Metropolis. In regard to incrustations i
pipes, he recollected having a pipe brought up from Swanage som
years ago, where the water was very chalky, which was reall
more filled with deposit than the pipe shown by Mr. Manserg
In fact there was not more than one-fourth of the cross-section
area of the pipe available for the conveyance of water. Wit
regard to the water-supply received from the Thames, 2 or 3 yea
ago he had cut out a 24-inch pipe in Hyde Park which had bee
in since 1819, and was in a perfect condition. A few nodul
were found inside, but practically the capacity of the pipe had n
been interfered with in the least, and the pipe was in as go
condition as when put in. Of course the pipe had always co
veyed filtered water, and possibly its excellent state after so ma
years might be partly due to this fact.

Mr. Hawksley. Mr. Charles Hawksley, Past-President, mentioned that the to
of Whitehaven, which was supplied with very soft water from
lake, had its pipes laid many years before Dr. Angus Smith's proce
of coating was introduced, and the pipes were laid without a
coating. In the course of time—probably not more than 20 yea
—many of the 3-inch pipes had become almost completely fill
with deposit. From what Professor Campbell Brown said in
Paper, and also from the experience on the Vyrnwy line of pi

Mr. Hawksley.

it seemed advisable to put the filter-beds, where possible, at the commencement rather than at the termination of a pipe-line; but where that had not been done it certainly appeared desirable to make use of the existing pipe by repeated scrapings, at all events until it had become worn so thin that it would no longer serve its purpose, when, of course, it must be replaced by a new pipe.

Mr. Ellis.

Mr. R. E. Ellis had had some experience in the waterworks of Madras, and had seen limpets formed on such a scale as to render it barely possible to see through a 7-inch pipe. The deposit was not of a calcareous nature; it was of the limpet form, and the smell from it when it was removed was very offensive. The curious thing was that though the same water was eventually pumped out in the form of sewage through an iron main, there was no deposit of any sort in that main, which was as clean then as on the day it was put in.

Sir Guilford Molesworth.

Sir Guilford L. Molesworth, K.C.I.E., Vice-President, had inspected the waterworks at Singapore, and could corroborate the statement as to the condition of the water there. It was of a dark yellow colour, and smelt abominably. It was very satisfactory to find that the arrangements which had been made had the result of purifying that water.

Mr. Francis.

Mr. Joseph Francis remarked that there was one matter in which he had taken some interest in connection with the first Paper, namely, the protection of the inside of pipes by Dr. Angus Smith's process. Pipe-founders usually asserted that the coating would be found to be perfectly satisfactory, but unfortunately it hardly ever was so. Many of the pipes laid some years ago, soon after the first adoption of the process, were found to be in a perfectly satisfactory condition, but his experience was that, as now conducted, the process might be called a failure. Whether that was due to want of care in carrying it out, or to want of knowledge and attention in providing the proper ingredients in their right proportions, he did not know; but, as a matter of fact, pipes from all the large British ironfounders had serious defects in the coating. He had been told recently that in America a method of coating was adopted in which a solution of rubber was used; and it would be interesting to hear exactly how that was carried out, and with what success.

Mr. Brewster.

Mr. E. H. G. Brewster considered that a great deal depended on the quality of the iron of which the pipes were made. Papers[1]

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[1] Minutes of Proceedings Inst. C.E., vol. i. (1840) p. 70, and vol. ii. (1843) p. 171.

Mr. Brewster. by Mr. Mallet, read before the Institution many years ago, ga
particulars showing the necessity of paying attention to t
composition of the cast iron used for structures exposed to wate
and also pointed out that certain compositions decayed ve
rapidly in water and became soft. That was well known to ma
engineers, but not to all; and it was just possible that in so
cases where there had been failures in the pipes the compositi
of the cast iron had not been of a suitable character. As
illustration he might say that quite recently he had examin
two small cast-iron tanks, made by the same maker thou
probably at different periods, containing water of the Southwa
and Vauxhall Water Company. The water in both tanks h
been in constant agitation, and the tanks were continually bei
filled and discharged. One tank he had found to be full of lar
nodules similar to those which had been described, and the met
inside the tank was very soft. The other tank was practical
unaffected; it was merely slightly rusty. From what he had hear
and from his own observations, he thought the composition
the pipes themselves would have a good deal to do with the grow
of the nodules.

Prof. Brown. Professor Campbell Brown, in reply, remarked that althoug
Mr. Mansergh apparently held a different opinion from himself
regard to the wisdom of scraping, there did not seem to
really much difference between them. If he were advising
engineer, he would undoubtedly—if it were in the engineer's o
interests and in the interests of engineers as a body—advise him
scrape, because in that way a rather larger flow of water would
obtained. But if he were advising a Corporation, he did not thi
he would give such advice; because the use of the scraper wou
cause the water-pipe to have a shorter life, and it was just
question whether the advantage of having a little larger flow
water for a certain period was cheaper in the end than having
slightly less flow for some longer period. Naturally, an engin
was willing to put in pipes as often as they were worn
The deposits of lime came, of course, from the water, and could
scraped out without injury to the pipe. But it would be fo
that the metal of the pipe he himself exhibited had been chang
so that on the outside it would spoil the edge of a knife, while
the inside the knife would cut it. The reason why the lif
pipes was shortened by scraping was that the incrustation
tected them, somewhat in the same way as a layer of pitch
india-rubber did. By scraping it away, a fresh surface was
posed to the action of the oxidising water. The material of

Prof. Brown.

incrustation was supplied from the pipe itself and not from the water. With regard to the question of peat, he had attacked the problem patiently and slowly, applying, as far as possible, the principles of inductive reasoning. He had no preconceived theory. Some of his engineering friends had said the deposit was peat, but on examination he had found that it was not: it was connected with peat, however. The peaty waters getting iron from iron springs, the acids from peat helped to dissolve and keep in solution that iron, and formed a compound of carbonaceous acid with the iron, which flowed along the pipe. Wherever he happened to have found peat particles in the water there was no deposit of slime. He had found undoubted peat in a sample of water taken from a tap in Glasgow, and there was no slime in the Glasgow pipes. The "limpets" were often apparently symmetrically placed, and that had been attributed to microbes, to electricity, and to various other causes. If a solution of Epsom salts was taken and a little gum put into it, and it was then spread over a sheet of glass and allowed to crystallize, the crystallization would start at uncertain points. If it were touched with a piece of glass rod it would start crystallizing at each of the places touched; if there was a little dirt on the place it would begin there, and if a fly brushed it with its wings it would begin there. That was neither electricity nor microbes. It was a process of crystallization; and he took it the formation of the incrustations was of a similar kind. Many things would start it—roughness in the iron pipe, a pin-hole in the pitch, and so on. The object of the coating of pitch was merely to prevent the water from getting at the pipe, and if the coating was imperfect the process failed. If the india-rubber stuck to the pipe it would not fail. The pitch failed because perhaps it was not of the proper composition, and was not properly applied. He thought Mr. Joseph Parry had solved the difficulty of putting on pitch properly, and 50 years hence the pipes laid down by him would be found as good as they were to-day. The Angus Smith coating applied by Angus Smith was satisfactory; but, put on empirically by contractors who only knew the words in the contract, it would not be satisfactory. The incrustation was a very small matter. The diminution of the sectional area of the pipe was relatively large in a small pipe, which might be completely blocked; but in a large pipe—4 feet or more in diameter—it was not of great importance. The Rivington pipe-line, laid 50 years ago, had such a dense incrustation in it that the water could not get at the iron; and it was not increasing. To scrape that off would be a mistake, because it would simply

Prof. Brown. start the oxidation again. The choking of the Vyrnwy pipes wa not due to such incrustations. Limpets were dotted over them but did not seriously impede the flow, the impediment being du to something else. What that was he had discovered by slow investigation, and he had described the process of growth of th deposit in his Paper. His investigations touched upon a matte of wider interest, a question connected with the philosophy of life If Winogradsky's views had been correct, there would have bee an example of living organisms deriving their energy from th oxidation of mere mineral matter. These views had been prove incorrect; and although certain mineral matters were necessar ingredients of food, an example was still wanting of a living thing which did not derive its vital energy from the consumption o some carbon compound.

Mr. Blount. Mr. BLOUNT, in reply, expressed his obligation to Mr. St. Georg Moore for the description he had given of his experience. Evidentl that plan was efficacious; and he believed that if Mr. Moore adopte the method of distributing described in the Paper, the advantage h had noticed would be enhanced. The trouble at Singapore ha been quite as serious as Sir Guilford Molesworth had stated. Mr Tomlinson had attacked the problem differently from the metho adopted by Mr. Chadwick and himself, but on the same principle and with equal success. With regard to the remarks of Professo Campbell Brown, the quantity of iron used was 20 lbs. per millio gallons, but with a better method of aerating the water in th revolver, this quantity was now increased. The object in vie was, in great measure, the oxidation of the impurities in th water, and for this purpose the complete aeration of the water wa desirable, if not essential. The only reason for using a fairl large orifice was to avoid accidental stoppage; even when thi somewhat large orifice was employed, the loss of head was no serious, and, on practical grounds, the larger size was preferabl Whether a large or a small orifice was adopted, the aeration wa sensibly perfect. The action of the iron was, in some degree, du to the precipitation of ferric hydroxide derived from the oxidatio of a ferrous salt, but more important was the action of ferro hydroxide as a carrier of oxygen. The proof of this lay in th fact that the organic impurities were not merely precipitated b oxidised, a result not attained by aeration alone.

The President. The PRESIDENT remarked that, while he knew nothing abo deposits in water-pipes, he knew a good deal about corrosi and fouling on iron ships; and he entirely agreed with Profess Brown's remarks as to the serious obstruction presented by

The President.

growth of the kind described in his Paper on a surface past which water had to flow. It was extraordinary what an enormous increase in resistance might be found when the bottom of a ship was not apparently very dirty. Not long ago, in a vessel for the design of which he had been responsible, there had been a difficulty in getting the intended speed; and although he had ceased to be in active work, he had analyzed the matter and had come to the conclusion that the cause was a dirty bottom. He had been told that was impossible; but he had urged those who succeeded him to make an investigation; and he might say that when the bottom had been scraped and painted, the same speed had been obtained with 5,700 I.HP. less. It seemed to be only a little detail, but it meant a good deal to the performance of the ship, as well as to the credit and the comfort of the designer. That result had been due not to absolute dirtiness of bottom, but simply to a roughness of surface, which had at first been looked upon as comparatively unimportant. In such a case an apparently trifling growth might have marked effects.

Correspondence.

Mr. Appleyard

Mr. Rollo Appleyard remarked that engineers had hitherto handled in too empirical a manner the problem dealt with by Professor Campbell Brown. It would be interesting to have Professor Brown's opinion on the important question of the extent of the corrosive action corresponding to each class of deposit, and as to what connection, if any, existed between corrosion and deposit. If slimy growths proved to have a corrosive effect, the slime in surface water and on water surfaces would be of importance in considering the corrosion usually regarded as being due to simple oxidation at the wind-and-water line of ships, tanks, and all partially submerged iron structures. In regard to preservatives there appeared to be only one point upon which there was universal agreement, namely, that the iron must be freed from rust, scale, grease, and moisture, before applying the protective coating. Although this cardinal principle was well known, it was far too frequently neglected. The methods of preparing the surfaces of iron structures for painting were altogether crude, and the preservative compound was often blamed for the fault of the person who applied it; hence, also, the anomalous results obtained with the

Mr. Appleyard. same compound. With regard to india-rubber as a preservative fo iron pipes, it was somewhat difficult to see how this substanc could be used except as a solution in naphtha or its equivalent A solution of india-rubber in naphtha was not very stable, especi ally in contact with metals; the question of durability woul therefore have to be studied before adopting this method. It di not appear to be generally known that ebonite could be vulcanize upon iron, forming complete protection and, of course, insulatin the iron. This method might be useful in special cases wher complete protection was required, and where expense was not o prime importance.

Mr. Bruce. Mr. A. Fairlie Bruce desired to offer a few observations in th light of his experience as Water Engineer to the Bomba Municipality. The water-supply of Bombay was derived fro three artificial lakes: Tansa lake[1] situated on the mainland at distance of about 57 miles, and Vehar and Tulsi lakes in the Islan of Salsette, about 13 miles and 16 miles respectively from the city The gathering-ground of the former was covered chiefly with tea jungle, but had some small areas of paddy-field at its norther extremity, and a few small villages scattered over it, at distance of 1 mile to 10 miles from the lake. The two latter lakes wer completely surrounded by a thick mixed jungle, and throughou both areas there was a rank growth of grass during the monsoon frequently burnt by jungle-fires in the dry weather. Owing t the great area and depth of the Tansa lake, respectively 5½ squar miles and about 100 feet at the maximum, the sedimentation wa much more perfect than in the other lakes, and the quality of th water was consequently much superior. When the reservoir wa originally constructed, its area was only imperfectly cleared o timber, and he had taken advantage of the unusually low level o the lake in the famine year of 1899 to saw off at the water-leve and remove the bulk of the trees, whereby a marked diminution o the growth of algæ had been effected, with a correspondin improvement in the quality of the water. The water of the Tul and Vehar lakes contained large quantities of algæ, particularl after the close of the monsoon and again in the hot weather, fro the end of March until the burst of the monsoon in the middle June. There was also a large quantity of weed at the upper end the Vehar lake, which, though it might have a somewhat prejudici effect on the quality of the water when it died, probably had th

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[1] "The Tansa Works for the Water-Supply of Bombay," by W. J. B. Clerk Minutes of Proceedings Inst. C.E., vol. cxv. p. 12.

Mr. Bruce.

compensating property of absorbing a considerable quantity of algæ, which was probably consumed by the low forms of insect life of which the weed formed the habitat. The Tansa water was conveyed to Bombay partly by means of a built aqueduct and partly in 48-inch pipes; that of the Vehar lake in a 32-inch and a 24-inch main, and the water from the Tulsi lake in a 24-inch main. None of these waters—varying in hardness between 1° and 2°—had any pronounced action on cast iron, only forming a thin scale of rust after the disappearance of the protective coating; and the only cases in which partial obstruction had occurred had been in a number of 3-inch mains laid about 45 years ago, which, though as a rule under nominal pressure, had no appreciable flow through them for 16 hours or 17 hours a day, and in which the conditions were consequently favourable for the deposition of any silt contained in the water. The Tansa 48-inch pipes, which had been laid for about 12 years, only showed a reduction of discharge of about 6 per cent. to 7 per cent. below that calculated by Darcy's formula taking the value of ζ as 0·0034. The Vehar 24-inch main, which was about 18 years old, showed a falling-off of about 18 per cent. The Tulsi 24-inch main, after being laid for 24 years, had lost 32 per cent., but passing a scraper through it 2 years ago had led to an increase of about 13 per cent. in its discharge; this gain had now, however, been lost again. The Vehar 32-inch main, which had been laid for 44 years, had lost about 34 per cent. of its carrying-capacity; it seemed to have reached this stage about 10 years ago, and certainly during the past 6 years, during which it has been under his charge, it had shown no further signs of internal deterioration. As far as his experience went, both in Bombay and elsewhere, he was of opinion that, in the case of large mains with a constant flow through them, the tendency was towards a low rate of diminution of discharge, which gradually accelerated as the coating disappeared, until it reached about 20 per cent., after which it again decreased until stability was attained at 30 per cent. to 40 per cent. below the rate of discharge when new. Where pipes had been laid in dry unpolluted soil there had been but little external corrosion in the Bombay pipes; but in view of a proposal to alter the line of the 32-inch main, which was at present laid along the embankment of the Great Indian Peninsular Railway for a distance of about 6 miles, it had recently been subjected to careful survey by a Government Commission of which he was a member, with a view to ascertain, among other things, to what extent it would be suitable for relaying. For a distance of about 2½ miles, where it was laid

Mr. Bruce. in damp soil containing about 20 per cent. of vegetable matter, i was found to have been subjected to a severe form of galvani action, with the result that the metal had been eaten away in a wavy form and rendered so soft that it could be cut with a knife the particles of iron being transferred to a crust of mingled eart and iron oxide, 2 inches to 3 inches thick, adhering firmly to th exterior of the pipe. Several pipes on this section had burst, th thickness of sound metal left being reduced to less than $\frac{1}{8}$ inch and a large piece in each case being blown out of the bottom o the pipe. On the other hand, in dry earth the metal had show little or no signs of corrosion and the maximum depth to whic oxidation had penetrated outside of the stretch of polluted soi was about $\frac{1}{4}$ inch. In another length of about 1 mile to the nort of the railway, where the main had been subjected to the action o salt, the metal had peeled off in flakes $\frac{1}{16}$ to $\frac{1}{8}$ inch in thickness due possibly to galvanic action, set up by the salt between layer of metal of slightly different composition, leading to the forma tion of oxide between them, which gradually split them asunde While the Tansa water had always proved satisfactory, and th Vehar water generally so, that from Tulsi had always give more or less trouble during the period of warm weather, bot after the cessation of the rains, and in the three months o hot weather which preceded them. A rise of a few degrees i temperature had a marked effect, and the improvement due to day or two of cloudy weather was often very noticeabl It having been observed that the water deteriorated to a ver appreciable degree in transit from the lake to the filters o Malabar Hill, it had been determined to take samples from ai cocks along the line. For the first 3 miles, where the main w protected by jungle from the effects of the sun's rays, no appr ciable difference had been observable between the samples draw from the pipes and the water in the lake; but for the remaind of its length, where it was more or less exposed, each successi sample had shown a steady deterioration, an increase in the fr ammonia, and a gradually deepening yellow shade, accompani by a faint sickly odour. When scraped, the pipe had been fou to be coated with the black slime alluded to by Professor Brow containing sulphide of iron, about 1,800 colonies of cocci per cu centimetre, and a variety of low forms of vegetable life. It h been proposed to cover this portion of the main with 2 feet of ea in order to protect it from the sun, but the sanction of the C poration has not yet been accorded to the necessary expenditu Neither the Tansa nor the Vehar water had been found to

Mr. Bruce.

affected in the manner above described, owing probably to the absence of iron from these waters, as well as to the smaller quantity, and, some difference in the quality of the vegetable matter contained in them. On arrival at Malabar Hill, the Tulsi water was passed through copper-wire screens having nineteen wires per lineal inch, and then through a settling-tank, and was afterwards filtered through sand filters of the ordinary type. Experience had shown that no advantage was gained by reducing the rate of filtration below 600 gallons per square yard, while the efficiency began to fall off after a rate of 700 gallons was attained. The rate adopted had therefore been between these two figures, with satisfactory results. The length of time during which a filter would work before the head necessary to pass water at the above rate exceeded 2 feet 6 inches, when the filter was cleaned, varied greatly with the season of the year, the minimum being about 12 days, the maximum 40 days, and the mean about 21 days. Before being again put in use, the filters were allowed to remain empty for at least 48 hours. The filtering-area has hitherto only been sufficient to filter about 55 per cent. of the water received, the balance being merely settled, and mixed with the filtered water in the clear-water reservoir. Soon after taking over charge of the works he had pointed out the impropriety of such a system, and had designed an extension by the addition of three new filters, to enable the whole supply from this source to be filtered. Considerable delay had occurred in obtaining sanction for the necessary expenditure, but the filters were now in course of construction, and it was hoped they would be in operation in another year. Professor Brown had done good service in calling attention to the defects of Dr. Angus Smith's solution, which afforded but a temporary protection to castings, and any improvement upon it would be welcomed by water-engineers. The proposal to dip pipes a second time at all events offered some hope of improvement, and appeared to be worth trying.

He was inclined to disagree with the view expressed by Messrs. Chadwick and Blount, that in order to get rid of the lower strata of impure water it was necessary to discharge them through an outlet at or near the bottom of the reservoir. It appeared to him that a reservoir was precisely similar to a large pool in the course of a river, through which there was a steady flow down to the very bottom. As water flowed in from tributary streams and passed over the waste-weir, the current, though it might be imperceptible, must extend to the bottom layers, which rose and passed over the weir. Messrs. Chadwick and Blount also lost sight of the action

Mr. Bruce.

ANALYSES OF BOMBAY WATER.

No.	Source of Sample.	Grains per Gallon.		Parts per Million.		Remarks.
		Total Solids.	Chlorine	Free Ammonia.	Albuminoid Ammonia.	
	Vehar Water.			*October*, 1902.		
1	Vehar Lake.	7	1·1	Trace	0·194	Large numbers of algæ present; fairly clear and bright. Nitrites—Nil.
2	Inlet-channel to the Bhandarwada Reservoirs (Unfiltered).	7	1·1	Nil	0·186	Large numbers of algæ present, otherwise clear, bright and free from sediment. Nitrites—Nil.
3	Filtered channel of Filter No. 2.	5	1·1	Nil	0·056	Clear and bright. (Rate of filtration 490 gallons per square yard per 24 hours.)
	Tansa Water.					
1	Tansa Lake.	8	0·7	0·04	0·052	Fairly clear and bright. Nitrites—Nil.
2	48-inch main at Chinchpokli.	7	0·65	Nil	0·032	Clear and bright. A very pure water. Nitrites—Nil.
	Tulsi Water.					
1	Tulsi Lake.	9	1·15	Nil	0·174	Slightly coloured. No algæ present. Nitrites—Nil.
2	Receiving well at Malabar Hill Reservoirs. (Unfiltered.)	10	1·15	Nil	0·108	Faint brown tinge. No algæ present. Nitrites—Nil.
3	Filtered channel of Filter No. 4.	8	1·15	0·112	0·068	Fairly clear and bright. (Rate of filtration 633 gallons per square yard per 24 hours.)
	Tulsi Water.			*January*, 1903.		
1	Tulsi Lake, Jan. 26.	7	1·1	nil	0·160	Faint brownish tinge, fine particles of vegetable debris present, but no algæ.
2	Receiving well at Malabar Hill. Jan. 13. (Unfiltered.)	7	1·0	trace	0·196	Faint brownish tinge; no smell; no algæ. Nitrites and Nitrates absent.
3	Filtered water channel of Filter No. 1. Jan. 13. Filter working since Jan. 3.	6	1·0	nil	0·06	Clear and bright; no sediment. (Rate of filtration 627 gallons per square yard per 24 hours.)
	Vehar Water.					
1	Vehar Lake, Jan. 26.	7	1·0	nil	0·244	Slightly coloure and contained larg numbers of algæ. Nitrites and Nitrate absent.

ANALYSES OF BOMBAY WATER—*continued.*

No.	Source of Sample.	Grains per Gallon. Total Solids.	Grains per Gallon. Chlorine.	Parts per Million. Free Ammonia.	Parts per Million. Albuminoid Ammonia.	Remarks.
			January, 1903 (*cont.*)			
	Vehar Water (cont.).					
2	Inlet-channel to the Bhandarwada Reservoirs. Jan. 16. (Unfiltered.)	7	1·0	nil	0·172	Fairly clear and bright very few algæ. Nitrites and Nitrates absent.
3	Filtered-water channel of Filter No. 5. Filter had been at work for 13 days.	6	1·0	nil	0·078	Clear and bright. (Rate of filtration 463 gallons per square yard per 24 hours.)
	Tansa Water.					
1	Tansa Lake. Jan. 16.	6	0·65	0·034	0·104	Fairly clear and bright; a few algæ present.
2	48-inch main at Chinchpokli. Jan. 23.	6	0·65	nil	0 076	Fairly clear and bright. A few fragments of vegetable débris, but no algæ. Nitrites and Nitrates absent.
			May, 1903.			
	Tulsi Water.					
1	Tulsi Lake, May 13.	7·0	1·2	0·024	0·298	Many algæ present. Iron 0·001 parts per 100,000.
2	Outlet-tower at Tulsi Lake, May 13.	7·5	1·2	Trace	0·402	Algæ very numerous. No yellow colour. Iron 0·005 parts per 100,000.
3	Receiving well at Malabar Hill, May 12. (Unfiltered.)	8·5	1·2	0·176	0·196	Deep yellow colour. Very few algæ. Iron 0·14 parts per 100,000.
4	Filter No. 1, May 12. (Filtered.)	7·0	1·2	Trace	0·132	Fairly clear and bright. No yellow colour or sediment. Iron 0·03 parts per 100,000.
	Vehar Water.					
1	Vehar Lake, May 14.	8·0	1·2	Trace	0·522	Slightly coloured. Algæ abundant.
2	Outlet-tower at Vehar Lake, May 14.	8·0	1·2	0·04	0·520	
3	Entrance-channel to Bhandarwada Reservoir, May 15. (Unfiltered.)	8·0	1·2	Trace	0·160	Some algæ present.
4	Clear-water channel of filter. May 15.	7·0	1·2	Trace	0·058	Clear and bright. No sediment. (Rate of filtration 450 gals. per sq. yard.)
	Tansa Water.					
1	Tansa Lake, May 16.	8·0	0·7	0·056	0·096	Fairly clear and bright. A few algæ present.
2	48-inch main at Chinchpokli. May 26.	8·0	0·7	Nil	0·066	Clear and bright. No algæ.

Mr. Bruce. of wind, which almost invariably accompanied heavy rain, an which caused a turn over in the water of a lake or reservoir It was noticeable that the Bombay water usually showed sign of deterioration for a short period immediately after the firs burst of the monsoon, which might be attributable to this cause Some typical analyses of the Bombay water-supply at differen seasons of the year, namely, in October, in January, and in May were given on pp. 60 and 61, which might be of interest.

Mr. Campbell. Mr. A. H. Campbell pointed out that, while Messrs. Chadwic and Blount's Paper referred mainly to tropical conditions, thos conditions had their counterpart at home, where the standard of sanitation was keener than abroad. The action of large communitie in going far afield for a suitable source of water-supply, while i secured a gathering-ground removed from the pollutions inciden to inhabited areas, did not deliver the water-engineer from trouble of an alternative kind—for instance, that due to the decay of vegetation; and if thereby organic impurity was not introduced int the water to an injurious degree, probably discoloration occurred and the water had a brownish, dirty-yellow hue, which, if no hurtful to the body, was certainly offensive to the eye. Wate obtained from moorlands where peat abounded was specially liabl to this discoloration, as was also water derived from land of marly description. It had been his duty about 10 years ago, a engineer of the waterworks of a town in the midlands, to appeas the local animus arising from the turbidity of the town water supply after rainfall. The cause of this turbidity was probabl twofold. First, the soil of the gathering-ground was a deep red coloured marl; secondly, there was a good deal of woodlan upon the catchment-area. During the fall of the year, and at othe flood times, very turbid water was obtained. Moreover, as th storage-capacity was limited, and the filtering-area was small, th conditions were probably as unfavourable as could be. The wate supplied under such conditions was neither palatable nor inviting i appearance. The storage-reservoir had been nearly exhausted by long period of drought, and there was only about 10 days' availabl supply in the reservoir when rain came to relieve the extremity. I had therefore become necessary to take in the water as it came dow in flood, trusting to the sand filters to reduce, if not to remove, th impurities. But the action of sand filters of ordinary compositio was helpless to remedy the defect in the purity and appearance the water under such conditions. Of course, increased storage an larger filtering-area, service-reservoir equipments, etc., would hav assisted, but time would have been needed for the application

Mr. Campbell.

those measures. They would have been ultimate palliatives rather than the immediate correctives which the case urgently demanded. The plan adopted had therefore been to uncover the sand-bed of the filter to a depth of about 15 inches, and to embed at that depth in the filtering media a 6-inch layer of what was then called "porous carbon," but which was really a carbonaceous powder, granulated to about $\frac{1}{8}$ to $\frac{1}{4}$ inch size. The top layer of sand was then replaced, and the water was turned on to the filter as before. The change at once wrought by the introduction of this material was very marked, the turbidity being quite removed. The material had remained ever since in the filters, and continued to do the same good service. Another instance of discoloration was the Moorfoot supply to Edinburgh, which was often discoloured and turbid after rainfall, due to a peaty gathering-ground, inadequate storage, and insufficient filtering-area. Again, the submergence of large valleys, containing perhaps hamlets, woodlands and large tracts of rich arable land, must necessarily involve the presence of decomposed organic matter in the water, and necessitate exceptional methods of treatment. Waterworks engineers had not only to satisfy chemical and biological requirements, but must pay attention to the appearance of the water for drinking purposes. The practice of the engineers of the Metropolitan Water Companies of testing for colour in a tube about 2 feet in length was good; and it was highly creditable to the management of the filters of those companies that the waters from some at least of their sources of supply could be clarified so as to pass satisfactorily such tests. With regard to the application of the theory of aeration to the purification of sewage, aeration of sewage, or of any impure water, by exposing it in fine drops to the atmosphere, was becoming very general in sewage-works, and devices for the purpose were numerous. He had recently had practical proof of the efficacy of passing effluent sewage, after precipitation of the sludge, over a series of weirs in a thin, filmy stream; and for the purpose of sewage-purification there was no doubt that repeated aeration of the liquid was of the highest value. The clarification and purification effected at the sewage-works in question was demonstrated by the support of fish life in a small vessel of effluent, unchanged for weeks.

Mr. Cornish.

Mr. J. E. Cornish observed that Professor Campbell Brown's Paper was evidently the result of minute observation on an important subject which had probably never before been so clearly dealt with. In determining the proper diameter of pipes for the distribution of water, the question treated in the Paper, though of the greatest

Mr. Cornish. importance and one requiring a special study for every quality o
water, was too often neglected: with the result that mains ha
frequently to be replaced at great cost before they were half wor
out. He was pleased to find that the Author did not approve o
the removal of incrustation by scraping. There was at presen
too great a tendency to rely on this process, and cases had com
under his observation in which damage had resulted fro
its use. In several cases known to him the results of deposit
had coincided very closely with those described in the Paper
He had had to remove, 38 years ago, a considerable quantit
of 8-inch lead pipe in connection with the Rouen waterworks, sai
to have been laid more than 400 years. The water it delivered
which flowed from a spring in the chalk, was beautifully clear an
bright, and contained a small amount of sulphate of lime. Th
inner surface of the pipe was very evenly coated to a thicknes
of about $\frac{3}{8}$ inch with an exceedingly hard deposit of fairl
smooth surface, which did not obstruct the flow of wate
to a much greater extent than the proportionate reduction o
the sectional area. The Author was quite right in laying grea
stress on the advantage of a good coating for pipes. Th
water of the Nile had a considerable effect on uncoated cast iron
Only a week previously he had had a piece cut out of a 26-inc
main which had been in constant work for 43 years. The coatin
was still perfectly good, and the iron was hardly affected on it
internal surface, but there was a certain amount of rough deposit
and in a piece about 6 feet long there were three mussel-shell
each over 4 inches in diameter, firmly adhering to the inner surface
the pipe was used for the delivery of unfiltered water from a pum
and the water passing through it had always been straine
beforehand. He hoped the Author might continue his useful an
interesting observations, as the subject was by no means exhauste

Having had many years' experience in connection with the filtr
tion of water from the Nile, he had read with interest the metho
adopted by Messrs. Chadwick and Blount in dealing with wate
highly charged with vegetable matter. On the one hand, the
were probably few rivers whose water was more affected b
vegetable matter than were the upper waters of the Nile; on t
other hand, there was no other river in which the water aft
pollution was so much exposed to the beneficial rays of the su
Still, at certain seasons of the year, even at Alexandria, the wat
has a decidedly greenish tint from this cause, and, if stagnant, w
liable to rapid deterioration. The difficulty of dealing with th
water, as it arrived at Alexandria, was considerably increased

Mr. Cornish. its being heavily charged with clay in such fine particles that ordinary sedimentation had but little effect, and filters rapidly became choked. During the last 9 years many experiments had been made in order to determine the best manner of dealing with this water. About 3 years ago, Professor Bitter, who was conducting the experiments then, had come to the conclusion that, of the many systems which had been tried, the best results were given by slow sand-filtration after the water had been clarified by mixture with a solution of permanganate of potash, and passed through large sedimentation tanks of a special form. Designs had been prepared and the works were to have been begun in 1902, when it had been suggested that another trial should be made of a system of rapid filtration by mechanical means, after sedimentation with a solution of sulphate of alumina. Experiments continued for several months had proved that (1) with a speed of filtration fifty times as rapid as that of the slow sand filters, a better bacterial result was produced, together with a perfectly clear filtrate; (2) whereas, with the slow sand filters, a staff of some fifty persons would be required for cleaning the filters, with the rapid system the whole work was done by mechanical means; (3) with the slow sand filters, the film forming on the sand, and containing much vegetable matter, might remain stationary several weeks at a time, whereas with the mechanical filters, it was all washed away twice during the day of 24 hours; (4) the cost of the mechanical system was less than that of the slow sand filters. The result of these experiments, made on a quantity of 120 cubic metres (26,400 gallons) per day, had been that the rapid mechanical system had been adopted, and was now being carried out with a plant capable of filtering 36,000 cubic metres (7,918,000 gallons) per day. In these experiments, the most delicate tests had failed to discover any trace of the sulphate of alumina in the filtered water. He considered that the system described would deal with the waters referred to by Messrs. Chadwick and Blount in a more satisfactory way than the methods proposed by them.

Mr. Friend. Mr. A. P. Friend contributed some notes on the composition of Nile water, and the system of treatment which had been proposed for Cairo. As the Cairo waterworks had obtained a very pure water from wells, and in future would not require filters, it was unnecessary to study the question further; but the notes might be of interest. Every year about the end of June there arrived at Cairo what was called the "green water," which greatly interfered with the filtration. The quantity varied considerably in different years. It lasted

Mr. Friend. however, only 10 to 15 days, so that it had not been considered necessary to go to great expense in trying to deal with the difficulty In a bad year great expense was even now incurred in scraping th filters and renewing the sand. This "green water" contained a littl organic matter only in suspension, but a large quantity in solution The actual cause of the stoppage of filtration was the formation under the influence of the sun, of a highly nutritive medium, muddy and colloid layer composed of vegetable matter and fungus Settling and decantation was apparently of no assistance whatever The question of precipitation of this matter had been studied wit both the filtered and the dirty water when green. Quicklime ha been tried in sufficient quantity to precipitate all the carbonate o lime in solution, and had been found to assist the filtratio slightly. Other processes had been tried subsequently. Almost al the methods had produced a precipitate, more or less chloride, the undesirable constituents, by collecting the organic matter i suspension and solution. The water after such treatment wa clear and easy to filter. The most satisfactory agent had bee found to be sulphate of alumina or alumino-ferric, with newly slaked lime. The consumption of this agent for, say, 25,000 cubi metres (5,498,700 gallons) of water per day would be about 1½ to This process had been found to reduce in a marked degree the quantity of organic matter in suspension and solution. The green slim formed on the top of the water of the filters, and gave out a stron smell of stale fish. It increased very rapidly under exposure the sun, and then sank and covered the sand, which in a sho time became choked, and thereafter the filters ceased to work. it were possible to remove the slime from the sand, the questio would be much simplified; but this work, difficult in the daytim was impossible at night. A certain amount had been done scraping, skimming and continually changing the sand, but considerable expense, and with heavy loss of water. The water the filter had to be run away into the desert before cleaning t filters, and the calculated loss was at least 100,000 cubic metr (22 million gallons). The Nile water was at its worst when the co sumption was greatest, not only on account of the vegetable matt but also on account of the enormous quantity of alluvial matter suspension and solution. The cleaning of the filters greatly reduc the area available, at a time when it could least be spared. T green-water trouble was luckily of short duration, but the alluv matter continued for 4 or 5 months in diminishing quantity, a with it a certain amount of vegetable matter. The filtration this water had been very thoroughly treated by Mr. A. Munz

Mr. Friend.

Paris in a report written for the Water Company. Observations had been made on both Nile water direct from the river and water which had passed the filters; with the following results. The month of September, being the worst month of the year, had been chosen.

	Matter in Suspension. Grammes per Litre.
Water taken 6 September—	
1. In the middle of the Nile at a depth of 2 feet	2·295
2. At the intake of the Company	2·130
3. In the settling tanks	0·650
Water taken 18 September—	
4. In the middle of the Nile	1·945
5. At the intake to the settling-tanks	1·673
6. In the settling-tanks	0·370
Water taken from a filter—	
7. After the sand has been in 18 days	0·009
8. ,, ,, ,, ,, 74 ,,	0·006
9. In the clear water reservoir	0·012
Water taken in September from—	
10. Filter No. 5	0·005
11. ,, ,, 4	0·005
12. ,, ,, 3	0·010
13. ,, ,, 2	0·012[1]
14. ,, ,, 1	0·013[1]

The filtration had, therefore, eliminated nearly all the solids in suspension. The water was very slightly opalescent. This was difficult to get rid of, as the water was so slightly charged with carbonate of lime that the clay remained in suspension. If the water were less pure, the clay would be precipitated and the water would be clearer. It was impossible to eliminate the opalescence entirely even by filtering through paper. This good filtration was doubtless due to a large extent to the film of mud deposited on the filter, which was locally termed "limon." The thicker the layer of limon the better the filtration, as was shown by lines 7 and 8 in the foregoing Table. Besides the matter held in suspension, the Nile water contained also substances held in solution. In December this quantity amounted to 0·14 gramme per litre. This was very small, and showed the Nile to be very pure. The following were the various substances held in solution:—

	Grammes per Litre.
Calcium carbonate	0·086
Potassium nitrate	0·008
Magnesium chloride	0·003
Sodium ,,	0·009
Calcium sulphate	0·003
Silica and clay	0·031
Organic matter	0·003

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[1] Filter No. 2 was not working well, and filter No. 1 had just had new sand put on it.

Mr. Friend. Little improvement from the point of view of purity could expected from filtration. Any improvement desired would hav to be made by the introduction of some foreign substance. Th organic matter in river-water had two different origins, namel the residue of animal life— which in the case of the Nile was ver small, as there were no towns or villages to speak of above Cairo- and the residue of the vegetable matter, which in the ground forme acid bodies. All soils, even the most sterile, contained organ matter caused by the decomposition of vegetable matter. Th water, in passing through the soil, collected a small quantity the substance, which adhered to the limon already in the wate but was not very prejudicial. Many waters in America whic according to Humboldt, were pure and agreeable to the tast contained as much as 0·025 gramme per litre. These organ matters existed in the Nile water before and after filtration equall as they were soluble; and, however perfect the filtration, coul not be susceptibly diminished. To eliminate them it would necessary that the water should undergo oxidation; but this bein a slow process, the passage of the water over the filters would n give the result desired, which would be obtained only by restin on the filters in presence of air. But to obtain this result would be necessary that only a small quantity of water should let into the filter at a time, so that the sand was not covered bu only impregnated, thus enabling the air to circulate between th sand particles and produce oxidation. This would be out of th question, as the installation of such a system would require, for quantity of 25,000 cubic metres per day, an area of 370 acre and, moreover, it would be unnecessary. Oxidation could n take place in the submerged filters necessary to give the requir output. The water passing through the filters arrived at a pla where the medium was non-aerated, and, coming in conta with the limon containing organic matter, two effects might produced:—

(1) A simple dissolution of the organic matter in the lim which might be added to that already contained in the wat The following results, however, showed that the quantity did n increase during filtration:—

	Dissolved Organic Matter. Gramme per Litre.
Water taken at the pumping-station	0·0031
,, ,, ,, settling-tanks	0·0030
,, ,, ,, filter working 18 days . .	0·0029
,, ,, ,, ,, ,, 74 ,, . .	0·0031

(2) Conversion of nitrates and ammonia into nitrites by

Mr. Friend.

decomposition of the organic matter. The analysis showed that there was no appreciable quantity of nitrates. The quantities of nitric acid were:—

	Gramme per Litre.
Water taken at the pumping-station	0·0041
,, ,, ,, settling-tanks	0·0040
,, ,, ,, filter working 18 days . .	0·0040
,, ,, ,, ,, ,, 74 ,, . .	0·0041

Therefore nitrates had not been decomposed, nor nitrites formed. Ammonia showed a slight increase, due without doubt to the organic matter contained in the limon through which the water had passed. The following observations had been made:—

	Ammonia. Gramme per Litre.
Water taken at the pumping-station	0·000015
,, ,, ,, settling-tanks	0·000020
,, ,, ,, filter after working 18 days .	0·000022
,, ,, ,, ,, ,, ,, 74 ,, .	0·000025

The sojourn of the water in the settling-tanks being stagnant, a slight increase took place, owing probably to want of aeration. The passage through the filters produced a more marked effect, and it was shown that the filter, which had been longest in work, gave the larger quantity of ammonia. This was not due to the sand but to limon, which covered and partly impregnated it. The renewal of the sand, and the scraping off of the limon, reduced the quantity considerably. The examination of the sands in the filtering media gave the following results:—

	Gramme per 100.
Sand taken from underneath the layer of natural sandy soil of the desert	0·011
Sand of the filters No. 5, taken at a depth of 10 centimetres	0·008
Sand of the same filter taken at the surface after 10 days of work	0·056

These figures showed that the top portion of the sand collected the organic matter, which did not impregnate all the sand; it was therefore sufficient to scrape off only a thin layer at the top in order to clean the filter. The lower sand retained its purity, or even became purified of part of its original nitrates by the water passing through it. The ammonia forming at the surface of the filtering media from want of aeration in this submerged apparatus would become more abundant the longer the water was in contact with the filtering media. It increased, therefore, with the depth of the filter-bed. Formation of ammonia would also be less active

Mr. Friend. the quicker the water passed through the filter. Retention of th
water in the settling-tanks tended also to increase the ammoni
in proportion to the quantity of limon deposited. It was, therefor
necessary to have the filters as thin as possible, only sufficien
thickness being allowed to retain the matter in suspension
to scrape off frequently the limon deposited; to renew the san
when the limon had penetrated it; to avoid allowing the water t
remain long in the settling-tanks, and to clean these frequentl
The water taken at the pumping-station and also at the settling
tanks had contained more than 100 colonies of microbes. I
had been impossible to ascertain the exact number. The filte
which had been working 18 days had given an average of 2·
colonies from seven samples, and the filter which had bee
working 74 days had given an average of 1·4 colonies. Thi
showed that the filters eliminated a large majority of the microbes
averaging at least 97·5 per cent. and 98·5 per cent., which wa
as satisfactory as could be expected. The reason why so good
result was obtained with such rapid filtration was that the grea
majority of the microbes adhered to the particles of limon an
were deposited therewith on the surface of the filters. It woul
be noticed that the water of the filter in which the sand had n
been renewed for some time was the freer from microbes; for, a
already shown, the filtration was more thorough the longer th
sand had remained in the filter. The production of ammoni
was directly in the opposite direction. Summing up the result
of the observations it appeared (1) That the filtration which ha
the object of eliminating the matter in suspension sufficientl
fulfilled the object desired by eliminating the greater part
the limon and a very large majority of the microbes. (2) Th
the filters were powerless to change the chemical constitutio
of the water. (3) That the opalescence was inherent to t
chemical composition of the water, and indicated its purit
(4) That the only inconvenience experienced in the filters w
the production of some traces of ammonia, which was large
counterbalanced by the advantage of the elimination of t
microbes.

Dr. Kemna. Dr. Ad. Kemna, of Antwerp, observed that he had reviewe
at some length Professor Campbell Brown's work when publish
in the Report for 1901 by Mr. Joseph Parry on the Liverp
water-supply. At the same time he had taken into considerati
some work by American practical scientists, namely, Mr. Dan

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[1] *La Technologie Sanitaire*, 15 Aug. 1902, vol. viii. No. 2, p. 29.

Dr. Kemna.

D. Jackson and Mr. George C. Whipple, so that his review was a general article on growth in pipes. The interesting Paper by Messrs. Chadwick and Blount showed the powerful action of iron. Some experiments he had made in 1902 proved that the active part was the precipitated oxide. When a very yellow peaty water was agitated during a couple of minutes with ferric hydrate, and, after some subsidence run through a filter-paper, 80 per cent. of the organic matter was removed and the liquid was scarcely to be distinguished in colour from very pure distilled water, a column 1 metre long being of a deep blue. As destruction of the organic matter by oxidation was a slow process—the analytical method with potassium permanganate required at least 5 minutes' boiling—the very rapid action of ferric oxide could not be of a chemical nature. It was a purely physical one of absorption, like that of charcoal or of alumina. He had obtained the same results with precipitated alumina, where the fixation of the organic matter was clearly seen by the yellow coloration of the otherwise pure white precipitate. Carbonate of lime acted in the same way, but not so strongly. Aeration was now frequently resorted to in Germany for underground waters containing iron and sulphuretted hydrogen. The question had been discussed in 1902 at the Düsseldorf meeting of Gas and Water Engineers. The conflicting evidence could be explained, as he had shown elsewhere.[1]

Mr. Lowcock

Mr. Sidney R. Lowcock expressed his appreciation of the scientific way in which Messrs. Chadwick and Blount had obtained their data in connection with the aeration of polluted waters. Although he did not think there was anything new in aeration of polluted waters subsequent to their treatment by the Anderson process or otherwise, he was not aware of any details of experiments other than Mr. Scott-Moncrieff's and his own, giving the actual amount of aeration required. Some years ago he had seen the works for the water-supply of Worcester, where the water was taken from the Severn, which, rising in the Welsh mountains, received *en route* the crude sewage of Stourport, Bewdley, Bridgenorth, Shrewsbury, and other places. This water was treated by the Anderson system, and subsequently flowed along a shallow channel having a perforated bed, through the perforations of which air was forced under pressure; but he had been unable to obtain any definite information as to the quantity of air so supplied per gallon of water. The result, however, was quite satisfactory. He had had experience in the treatment of water in the district

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[1] Bulletin Société belge de Géologie, 1902, vol. xvi. p. 474.

Mr. Lowcock. adjoining Farnham, where the surface-waters were very similar t that mentioned by the Authors, being practically free from anima pollution, but highly charged with vegetable refuse, an becoming very offensive when stagnant. He was of opinion tha this condition of the water here and elsewhere was largely du to the enormous number of pine-needles, both on the surface an in the subsoil. These not only decayed extremely slowly, bu contained secretions which were largely antiseptic and hindere and to some extent prevented, the decomposition of other dea vegetable matter in the vicinity, as well as that of the needle themselves. Whether the hard spines on the edges of the leave of the screw-pines (which, of course, were not of the genu *Pinus* at all) had any similar action, except in so far as the must decay very slowly, he did not know. These surface-water were not used for dietetic purposes, and the nuisance arisin was obviated by cascading and by the promotion of circulation that was, of course, by increased aeration. The subsoil-waters i the same district, which were used for drinking purposes, containe a considerable quantity of vegetable organic matter, and also o iron dissolved out of the soil and held in solution by the vegetabl acids. By delivering these waters into an open reservoir over th lip of a vertical bell-mouthed pipe, the lip being some distanc above the top water-level, and promoting circulation in th reservoir by means of training-walls, sufficient aeration wa obtained, and the iron was precipitated in the form of ferruginou jelly. The supernatant water was readily filtered throug ordinary sand filters and stored in a service-reservoir, the resul being quite satisfactory. This would appear to have some bearin on the formation of the slime described by Professor Brown, an Mr. Lowcock would suggest that if the original stable conditio of the water containing iron held in solution by humus acids wa broken down by preliminary aeration as the water left the reservoi the deposit of iron could be made to take place before tl water entered the conduit and the action of the organisms i the conduit and pipes would be inhibited. Apparently, the actio of the organisms and the production of slime in the pipes was du to the water becoming more thoroughly aerated, and having i oxygen continually replenished, by its motion in passing along tl conduit. The analysis of the slime, which showed no ferro oxide but a large amount of ferric oxide, seemed to support th view and to show that the slime was the result of comple biological oxidation. Filtration, according to Professor Brow statements, did not appear to be an absolute cure, and

Mr. Lowcock.

thought this was because the filters were insufficiently aerated, and as a consequence, although they removed most of the organic matter and much of the iron held in acid combination with it, they did not break down the remainder by complete oxidation. In the treatment of tannery-refuse, when the whole of the waste waters were mixed together and consequently contained both animal and vegetable organic refuse, he had found that while chemical treatment alone gave an effluent which it was almost impossible to filter, if this effluent was thoroughly aerated and again allowed to precipitate, the second effluent could be readily filtered and a perfectly satisfactory result was obtained. With reference to Messrs. Chadwick and Blount's suggestions as to the aeration of sewage by passing it through perforated plates, his experience was that the endeavour to pass sewage or tank-effluent through small holes was most unsatisfactory and a continual source of trouble and expense. In addition to the physical difficulties, the biological difficulty would be that the organisms in the sewage would use up the oxygen immediately it was absorbed by the liquid, and therefore it would be impossible to aerate it thoroughly until the whole of the organic matter had been broken down, when the filter would not be required at all. Probably, before this could occur, a point would be reached at which the organisms, owing to lack of suitable environment and temperature, would cease to develop; but in order to reach this point the streams would have to be of such an enormous length as to render it quite impracticable. Besides this, the treatment of a septic effluent in the way suggested—and all sewage which had occupied any considerable time in travelling from the place of its production to the disposal-works was more or less septic—would give rise to an intolerable nuisance. He believed it was becoming generally recognized that the proper way to deal with a tank-effluent was to sprinkle it on to the surface of the filter intermittently, in small doses as quietly as possible, and to allow it to trickle slowly down in thin films over the surfaces of the grains of the material of which the filter was composed, the interstices being always full of air, so that the purifying organisms were cultivated on the surfaces of the grains, and could take up the oxygen they required from the air in the interstices, and destroy the organic matter in the films of liquid.

Mr. Nowroji.

Mr. Hormusji Nowroji had observed, in somewhat accentuated forms, all the three classes of deposits enumerated by Professor Campbell Brown. A striking instance of incrustation was furnished by a system of water-supply, inaugurated in 1772,

Mr. Nowroji. for delivering potable water to Fort St. George, Madras. The
system was still in operation, but the water was now used
only for non-domestic purposes. The supply was derived from
wells in an extensive stratum of sand, which extended from
a few feet above subsoil water-level to an unascertained depth
below the bottom of the wells. The supply was therefore wholly
abstracted from a sand stratum which was of a purely siliceous
character. Presumably the water was naturally filtered. There
was no trace of iron or acidity in it. Some of the cast-iron
pipes in this system had been removed during the construction of
a sewer about 20 years ago. There had been incrustation in the
pipes which occupied nearly one-half of their original area, and this
was the condition of all the pipes in the system. The incrustation
was hard and metallic, without any loose deposit of a vegetable or
earthy nature. Whatever little loose deposit there was appeared
to be disintegrated crust. Twenty years later, in 1903, he had
had another opportunity of examining the pipes in the same
locality; and the incrustation did not appear to have advanced
appreciably in that period. This supported Professor Brown's
observation that there was a limit to the growth of incrustation
These pipes had been in the ground, and had been conveying
water for the last 130 years. There was no record of thei
having been cleaned during that period. The second class o
deposit occurred in a remarkable degree in the Madras cit
supply, introduced in 1872, which was obtained from a larg
impounding-reservoir. The gathering-ground was covered mainl
with laterite, an indurated ferruginous clay, in a gravelly or mor
compact form; and there was cultivation as well as much natura
vegetation on the gathering-ground. The water naturally containe
some dissolved iron and much organic matter. The supply wa
unfiltered. The pipes had been coated before being laid; and th
deposit in them, which was mainly of vegetable origin, was of
fibrous appearance; in other respects it resembled peat. It som
times accumulated to such an extent as to block the pipe com
pletely. There was no incrustation on the inner surface of th
pipes, but there was a thin metallic scale of a dark colour, whi
retained its colour even after it had been scraped and exposed to t
air. The deposit occurred mainly in the small-sized pipes with lo
pressure. The obstruction to the flow of water caused by the depos
was so serious that 3 years ago the pipes had been cleaned on
extensive scale. The result of this operation had been short-lived, f
deposits were already forming in the cleaned pipes. The followi
conclusions might be drawn from the foregoing observations. I

Mr. Nowroji.

crustation in pipes could not be accurately described as a deposit; it was rather an outgrowth of the metal forming the pipe: it was not derived from any constituent part of the water, nor from any matter contained in it. On the other hand, contact with water of a definite character appeared to be a requisite condition of the growth of incrustation. It was the result of some chemical change in the iron of the pipe, under the action of water. In the century-old pipes supplying Fort St. George, incrustation had been noticed on the outside of the pipes also, mainly at the flanges, the pipes being flanged. The theory was that leakage at the joints must have promoted incrustation in its neighbourhood. Examination of the circumstances attending the two kinds of deposits warranted the assumption that non-acid and organically pure water favoured the growth of incrustation. The action of water characterized by acidity would be to corrode and eat into the iron, and not to transform it into a spongy excrescence like incrustation. The obvious remedy against incrustation was an adequate protective coating to the pipes. The second class of deposit was quite unconnected in any way with the iron of the pipes. It was caused by organic impurity in the water, particularly if there was much of it in suspension. The theory that the conversion of this matter into a fibrous and peaty-looking stuff was due to bacterial action appeared to be tenable. In Madras, as probably in many other towns in the tropics, the pipe-water emitted a strong odour akin to sulphuretted hydrogen during the hot weather. When water issuing from a tap possessed this peculiar smell, it was a sure indication of a deposit in the pipe. The smell, which occurred only in the hot weather, could be satisfactorily explained upon the theory that the deposit was due to bacterial action. In the tropics rain fell within a limited period each year, and then followed a long spell of comparatively rainless months before the hot weather reached its height. The impounding-tanks were filled during the rainy months with water loaded with animal and vegetable matter, which passed into the pipes where filtration was not adopted—as in Madras—and provided food for the sustenance of myriads of bacteria. After the cessation of the rains, the water in the impounding-reservoir underwent a process of sedimentation; the suspended silt acted as a precipitant, and carried with it the organic débris contained in the water. In this and other ways the water in the tank was gradually freed from the organic matter as the hot weather advanced, and to a corresponding extent the food which sustained the bacterial life in the pipes diminished until it reached an insufficient minimum, when the organisms died in

Mr. Nowroji. untold numbers, and imparted to the water the peculiar odou
mentioned. The correct remedial measure was to filter the wate
before it entered the pipes. The results which followed th
large expenditure in cleaning the pipes in Madras had been ver
unsatisfactory, and proposals were now afoot for filtering an
delivering the water at a sufficiently high pressure. Purity o
water and a sufficient pressure of supply were conditions inimica
to bacterial life. The water in the impounding-tank at Madra
had never been known to emit any objectionable smell, which wa
due to the circumstance that the irrigation-sluices were severa
feet lower than the town-supply sluice. Tanks which emitted
strong smell in the hot weather were, however, not uncommon i
Southern India. For the prevention of such smell, and also as
safeguard against the general deterioration of tank-water, th
measure usually recommended was a scouring-sluice at the botto
of the tank, which would pass as much as possible of the surplu
water. The most efficient treatment of water which emitted a
unpleasant smell was to aerate it. The question as to how to d
so economically and with little loss of head was not easy
solution. Speaking of the efficacy of aeration, a curious instanc
might be cited. He had been asked to report upon, and sugge
measures for, an extensive tank near a large town, which emitte
a very unpleasant smell every hot weather, and caused muc
discomfort in its neighbourhood. During the enquiry it had bee
elicited that, in the olden days, as soon as the smell becam
apparent a large herd of elephants belonging to the Rajah, who
palace stood at the margin of the tank, had been led into the tan
where they disported themselves, thus thoroughly agitating t
water, and this invariably resulted in the disappearance of t
smell in a day or two.

Prof. Brown. Professor Campbell Brown, in reply, remarked that he would s
corrosion was in the inverse ratio of the perfection of the depos
Mr. J. E. Cornish had mentioned a perfect deposit (p. 62), whi
would completely protect a pipe against corrosion. Slimy deposi
being quite porous, afforded no protection against corrosion, whi
was the effect of oxidation, assisted more or less by salts and ot
substances dissolved in the water. The Bombay waters quo
by Mr. Bruce, as well as the Fort St. George water and the N
water mentioned by Mr. Nowroji and Mr. Friend respective
were of great interest, and the difference between the T
water and the other Bombay waters was very important. It
to be wished that additional analytical details had been giv
particularly, in all cases, a minute observation of the reaction

Prof. Brown.

neutral litmus. This could be done either by means of neutral litmus-paper or by a filtered decoction very carefully neutralized. He had little doubt the Tulsi water showed an acid reaction. It would also be interesting to see the organisms in the various Bombay waters and their deposits, particularly those of the Tulsi water. Although in a comparatively small reservoir the action of wind and the flow of the water might be important, yet in a sufficiently large reservoir, such as a lake, it had been proved by observation and experiment that a much larger portion of the suspended impurities was discharged through an outlet near the bottom of the reservoir, than from an outlet a few feet below the surface. The variations in temperature in the British Isles were not wide enough to enable him to attribute substantially increased growth in pipes to the summer season. In hot countries, no doubt, the difference would be very marked; but the effect of temperature upon different kinds of agricultural growths would be different. High temperatures in the dark, as in pipes, would no doubt be chiefly objectionable in promoting the decomposition of dead organisms rather than accelerating the growth of living ones; while the growth of some would even be checked by a high temperature.

Messrs. Chadwick and Blount.

Messrs. Chadwick and Blount, in reply, thought that Mr. Fairlie Bruce, in expressing dissent from the arrangement by which the surplus water was discharged from the bottom of the reservoir, scarcely realised the peculiar conditions which obtained in the case of the Mare aux Vacoas. That lake was very shallow, not more than 6 feet or 7 feet deep at any point. It was originally choked with vegetation. The bottom was coated with a deep layer of peat-like matter, which communicated a dark-brown colour to the water. During heavy rain the incoming water of the tributary streams was relatively pure; it was at least free from vegetable matter. In the original state of the reservoir nearly the whole of this relatively pure rain-water escaped over the crest of the weir, leaving the strongly-charged substratum in store for distribution. In order to remedy this a Stoney sluice was introduced, large enough to discharge a moderate flood. Instructions were given to the man in charge that during heavy rain this sluice was to be raised sufficiently to prevent any overflow. The result of this was to discharge the lower strata of water, those most highly contaminated by long sojourn in the reservoir, whilst the relatively pure incoming stream-water was retained in the reservoir. The outlet to the district was also provided with sluices in tiers, one above the other, so that the

Messrs. Chadwick and Blount.

purest surface-water might be drawn off for use. There wa
however, another reason for the construction of the low-leve
sluice. It permitted of the water being lowered for the purpo
of removing the accumulations of dead vegetable matter from th
reservoir. These doubtless were the principal cause of the stron
contamination. During the rainy season, the water in th
reservoir was kept down to the lowest practicable limit. Th
inflowing streams supplied ample water for the wants of th
district. The water merely passed through the reservoir, withou
storage, and therefore with the minimum amount of contaminatio
By keeping down the water-level, the work of removing bot
living and decayed vegetation was greatly facilitated. The
could be no doubt that in the present case the system of drawin
the supply from near to the surface and discharging surplus wat
from the bottom of the reservoir was productive of good result
The water, which before the cleansing operations were undertake
was so charged with suspended gelatinous vegetable matter as
be practically unfilterable, became filterable. This result w
doubtless to some extent due to the removal of vegetation and th
products of its decomposition, but as it had not been possib
thoroughly to cleanse the reservoir, some share in the improveme
must be attributed to the method of discharging surplus wat
from the bottom and drawing the supply from the surface of t
reservoir. Messrs. Chadwick and Blount were prepared to lea
that the Nile water might require treatment different from th
which they had found effective for other tropical waters. Nile wat
carried with it its own defecating agent in the shape of finely divid
clay, and if this were coagulated by the addition of a precipita
such as sulphate of alumina, a great increase in organic purity mig
be expected. In the case of the waters with which they had h
to deal, the problem was not so simple; there the organic matt
needed something more than defecation for its elimination, a
they had been driven to a more drastic method. The observatio
of Mr. Friend were interesting as tending to show that t
"limon" present in the Nile water acted as a coagulant; it wa
matter of traditional knowledge that though Nile water w
neither pleasant to the eye nor good for drinking in its raw sta
yet when allowed to subside even in small vessels, its gross i
purities were deposited, and in their deposition much promo
the purification of the water from the more subtle forms
contamination. They ventured to dissent from Dr. Kem
suggestion that the purification of water by means of iron
solely due to the precipitating action of ferric hydroxide. T

Messrs. Chadwick and Blount.

o doubt occurred, but *per se* it could not account for the resolution f nitrogenous organic matter which was proved by their analyses. t seemed to them preferable to regard the change as brought about y the unstable state of precipitated oxide of iron, which served as n excellent carrier of oxygen. The ferric hydroxide finally formed vas a precipitant precisely as was alumina, but before this stage he oxide had acted as an oxidising agent. One of the waters nentioned in the Paper (that from the pond at Rowledge) was lerived from the very district mentioned by Mr. Lowcock, but the imilarity of origin did not connote identity of quality. It ppeared from Mr. Lowcock's communication that the water at arnham was aerated chiefly for the purpose of removing iron; hat by itself was not a difficult matter, and could be accomplished y simple means. The real difficulty arose when the iron was so ntimately associated with organic matter, probably as a complex on, that its oxidation and deposition needed persistent aeration. ven when common ferruginous waters were treated, it might be ound economical to use perforated plates instead of the ordinary ountains. Messrs. Chadwick and Blount admitted freely that he utilization of their apparatus for the treatment of sewage vould require experiments; they in no way put it forward as uitable in its present form, but believed that the principle was ound and that it might be applied for this purpose.

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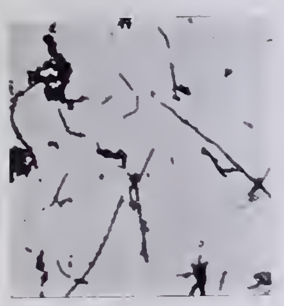
DEPOSITS IN PIPES AND OTHER CHANNELS.

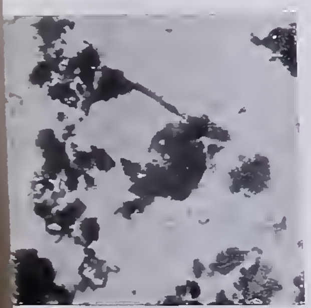
PLATE 1

FIG. 5.



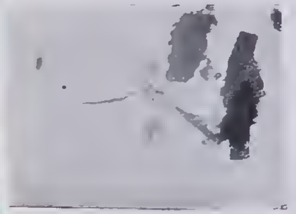
ROSARY FORM OF ORGANISMS.

FIG. 6



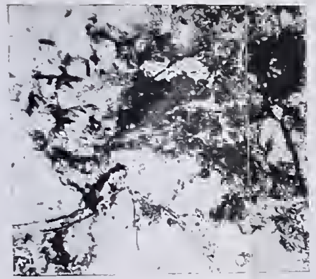
LO IRON-ORGANISMS IN SLIME (WATER NO. 12).

FIG. 7.



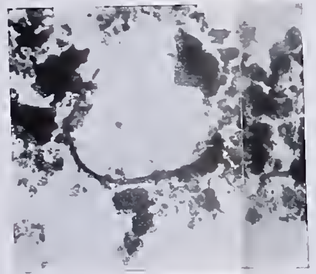
GROWING IRON-ORGANISM IN SLIME.

FIG. 8



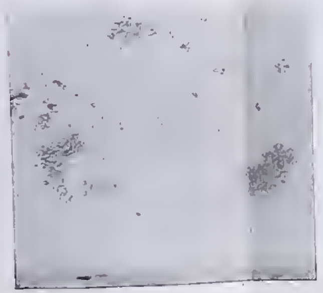
SLIME ORGANISMS IN WATER No. 2.

FIG. 9.



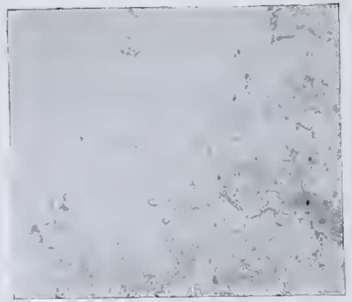
SLIME ORGANISMS IN WATER No. 12.

FIG. 10



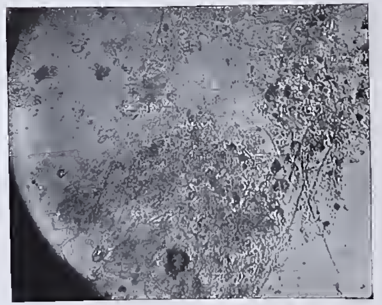
SLIME ORGANISMS IN WATER No. 12 (FIG. 9) AFTER REMOVAL OF IRON BY OXALIC ACID.

FIG. 11.



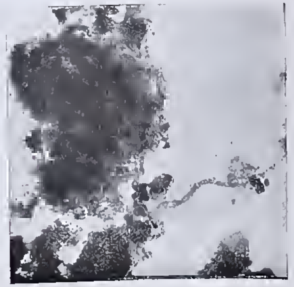
SLIME AFTER REMOVAL OF IRON BY OXALIC ACID.

FIG. 12



SLIME AFTER REMOVAL OF IRON BY OXALIC ACID AND STAINING.

FIG. 13.



SLIME ORGANISMS FROM WATER NO. 2

FIG. 15.

ORGANISMS FROM SLIME DEVELOPED IN THE LABORATORY.

MAGNIFICATIONS.

FIG. 4	350	DIAMETERS.
„ 7	150	„
FIGS 18-20	439	„

FIG. 14.

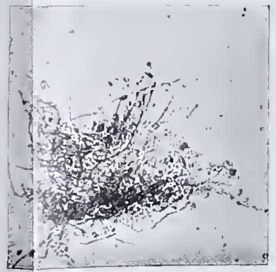
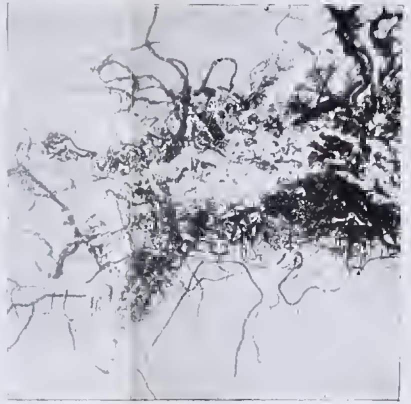


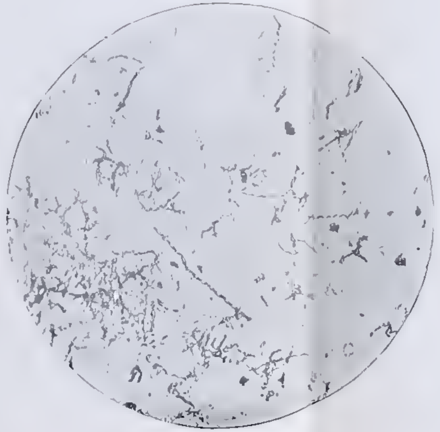
FIG. 13 AFTER TREATMENT WITH OXALIC ACID AND STAINING.

FIG. 16.



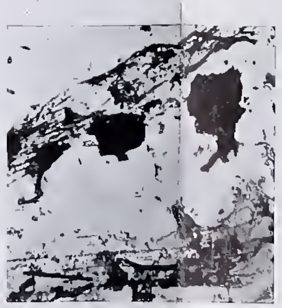
ORGANISMS DEVELOPED IN A STREAM.

FIG. 18.



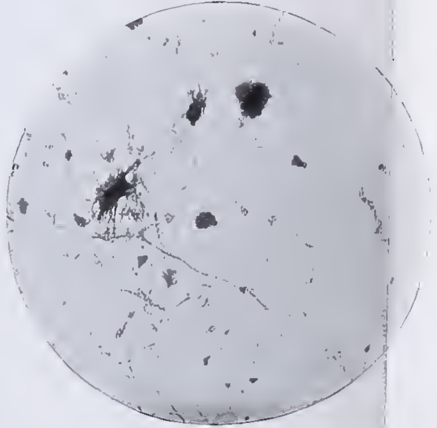
JELLY DEVELOPED ON NEW PIPES

FIG. 17



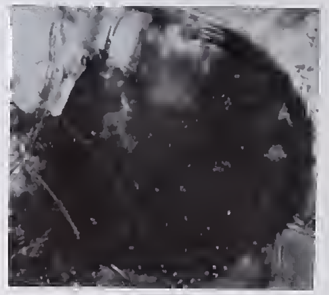
PEAT AFTER TREATMENT WITH OXALIC ACID.

FIG. 19.



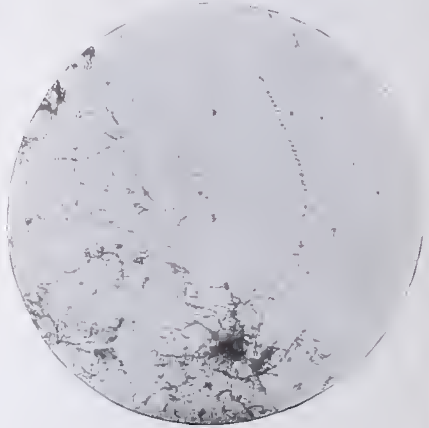
JELLY DEVELOPED ON NEW PIPES

FIG. 21.



FRESHWATER SPONGE FROM WATER No. 9.

FIG. 20.



JELLY DEVELOPING INTO SLIME.